PROCEEDINGS

OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS

VOL. 66 | JUNE, 1940 | No. 6, PART 2

RECOMMENDED PRACTICE AND STANDARD SPECIFICATIONS FOR CONCRETE AND REINFORCED CONCRETE

JOINT REPORT OF A COMMITTEE COMPRIZING REPRESENTATIVES OF

AMERICAN SOCIETY OF CIVIL ENGINEERS
AMERICAN SOCIETY FOR TESTING MATERIALS
PORTLAND CEMENT ASSOCIATION
AMERICAN CONCRETE INSTITUTE
AMERICAN RAILWAY ENGINEERING ASSOCIATION
AMERICAN INSTITUTE OF ARCHITECTS

Published monthly, except July and August, at Prince and Lemon Streets, Lancaster, Pa., by the American Society of Civil Engineers. Editorial and General Offices at 33 West Thirty-ninth Street, New York, N. Y.

Entered as Second-Class Matter, September 23, 1937, at the Post Office at Lancaster, Pa., under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on July 5, 1918.

Separate Reprints of Part 2, $1.50.

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PREFACE

For more than thirty years the design and building of concrete and reinforced concrete structures have been guided and deeply influenced by the work of Joint Committees as expressed in their reports.

These committees have been composed of members appointed by national engineering and technical organizations which were primarily interested in a safe and sound development of the use of concrete. The reports indicate broadly the progress that had taken place during preceding years and reflect the developments in the art in recommended practice and specifications.

The periods represented are clearly indicated in the reports. The first Joint Committee was organized in 1904, a time which marks approximately the beginning of reinforced concrete construction in this country. At that time concrete construction was principally in the hands of a few specialists whose methods varied with their experience. But by 1916, when that Committee submitted its final report, a great quantity of test data and an extensive literature had been accumulated which found expression in the recommendations of the Committee.

The first Joint Committee organized the available information into a code of practice based on fundamental principles and concerned itself with details only insofar as it was necessary to indicate the limits of sound practice. The essence of the first report is embodied largely in the sections on design which crystallized engineering practice and served as the basis for building code and specification requirements throughout the country.

The second Joint Committee, organized in 1920, was charged with the duty of preparing standard specifications for concrete and reinforced concrete, using as a basis the former Joint Committee report, with such modifications as were necessary to make its recommendations agree with current practice and such new data as marked progress in the art. The report submitted in 1924 in specification form indicated that a considerable advance had taken place in the method of producing concrete. The improvements had developed to the point where variability in the quality of concrete could be reduced by means of preliminary strength tests and controlling the quantity of mixing water through the control of the slump. The compressive strength of concrete could now be estimated with a reasonable degree of accuracy. On the basis of this improvement the Committee recommended a general increase in the ratio of working stress to ultimate strength of the concrete and permitted a corresponding increase in the steel stress where high yield point steel could be used. By standardizing grades of materials, methods of producing concrete, and the details of design procedure, the newly acquired knowledge could be utilized and

concrete construction placed on a more definite basis. The Committee completed its report after a series of field tests had demonstrated that its recommendations were substantially justified.

* * * * *

The present, or third Joint Committee, was organized in 1930 to study the extent and character of the advances in knowledge since the 1924 report, and make such recommendations with respect to practice and standard specifications as might be warranted in view of recent developments.

Of the advances made in recent years, relating to concrete as a material, the most significant are the increase in the strength of cement, a more widespread understanding of the basic principles of mixtures with increasing attention to field control, and an increasing use of ready-mixed concrete.

In the field of design, the major development has been the increased interest in rigid frame analysis which recognizes the essentially monolithic character of reinforced concrete construction and provides a more accurate method of stress computation and hence a more uniform factor of safety.

With these possible improvements in the quality of concrete and the new tools which elastic frame analysis places in the hands of the designing engineer, very material advances in reinforced concrete construction are now possible. In this report, the Committee has attempted to provide a means of applying this new knowledge through the combination of recommended practice and standard specifications.

* * * * *

The Committee was organized at a meeting held in Atlantic City, June, 1930, at which time there were present duly appointed representatives from the American Society of Civil Engineers, the American Society for Testing Materials, the American Railway Engineering Association, the American Concrete Institute, and the Portland Cement Association. In December, 1932, the American Institute of Architects was added to the group of organizations associated in the work of the Joint Committee.

The Joint Committee has held seventeen general meetings and numerous working committee meetings in the intervals between the general meetings. The reports of the working committees have been formally presented to the general committee for action in detail and the material has been assembled and edited by a committee appointed for that purpose.

In view of the extensive changes in form and substance of the report, as compared with those of the 1924 report, the Committee deemed it desirable to submit its work for criticism and discussion. To this end a progress report was given a limited circulation and presented for general discussion at a meeting in New York of the American Concrete Institute, February 26 and 27, 1937. The discussion brought out at that meeting and a considerable volume of written comments directed to the Committee have been carefully considered and such changes made in the report as seemed justified.

The last, or seventeenth, meeting of the Joint Committee was held in Atlantic City on June 27 and 28, 1938. At the conclusion of this meeting there still remained uncompleted a few items concerned with design and one on the

general treatment of the chapter on Waterproofing and Protective Treatments. The completion of these items and some major and minor changes in the text have been accomplished through one meeting of the Working Committee on Design and by the efforts of the editorial committee through correspondence and personal interviews with members of the Joint Committee. Revisions of Chapters 6 and 8 to which major additions and changes were made were approved by the working committees responsible for these chapters. These revised chapters and appendices, and other miscellaneous revisions of the text, were submitted to letter ballot of the 29 members of the Joint Committee on December 27, 1939. Twenty-six members returned ballots. The revised chapters and appendices received substantial majorities. Some of the members, however, indicated reservations with respect to individual sections or appendices, but the report as a whole was accepted by the unanimous vote of the 26 members returning ballots.

* * * * *

The Committee submits this report, not as the final word on concrete design and construction, but with a feeling that it reflects fairly the state of the art as represented by the best practice of the day.

Respectfully submitted,
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June, 1940

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C. L. POST (*appointed June 1932*), Chairman, Advisory Committee on Engineering, Federal Works Agency, Public Buildings Administration, Washington, D. C.

F. E. RICHART, Research Professor of Engineering Materials, University of Illinois

W. S. THOMSON (*resigned June 1932*), Chief Engineer, Kalman Steel Co., Chicago

American Society for Testing Materials

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INTRODUCTION

In submitting its report, the Committee thinks that it should not depend entirely on the specification form for presenting its recommendations. It believes that in covering those subjects on which the information is sufficiently crystallized, some advantage is gained by having the recommendation in the form of definite specifications. The report, therefore, consists of two interdependent parts: Recommended Practice and Standard Specifications. These two must be considered jointly as representing the recommendations of the Committee. Some of the more important departures from the 1924 Report are as follows:

Materials.—The recommendations provide for the use of high early strength cement and recognize that special cements may be desirable for special uses.

The subject of aggregates is treated much more comprehensively than was possible in the specifications of 1924. A working specification for general application is submitted with suggestions for modifications where necessary to meet special requirements.

The use of lightweight aggregates and the classification of aggregates on the basis of fire resistance are included.

Proportioning.—Emphasis is placed on durability of concrete. The increased strength of cement and improvement in concrete technology make it possible to produce concrete having a strength sufficient for ordinary design purposes with a water content too high for many types of exposure. The Committee is of the opinion that a classification or grading of concrete based on the character of exposure will be more generally useful than if based on the common requirements of minimum strength. Special emphasis is also placed on those factors which affect workability and the production of dense, homogeneous concrete.

Alternate Specifications.—Two types of specifications covering the proportioning of concrete are presented: One, in which the Contractor is required to produce concrete of a specified quality (exposure and strength considered) with considerable freedom of procedure within certain limits; and the other, in which the Engineer specifies the proportions required, including a minimum cement content. Where the strength is specified the test procedure is given together with a basis for enforcement of the strength requirements.

New Developments in the Art.—Developments such as ready-mixed concrete, mechanical vibration, and new methods of transporting, are covered either as recommendations or in the specifications.

Design.—The Committee has given special consideration to the increasing use of the principle of continuity and the elastic frame analysis in the design of reinforced concrete structures. Since reinforced concrete construction is essentially monolithic in character, it is felt that these newer methods are not merely refinements, but an attempt to produce a more rational and better balanced design. Several well recognized methods of frame analysis are

available to the designer and approximate methods have been developed that permit their use in ordinary building design without an undue amount of computation.

Columns.—The column provisions take into account the results of researches not available when the 1924 Report was published, particularly the American Concrete Institute column investigation reported in the *Proceedings* of the Institute, 1930–1933. The safe loads on columns are based on the ultimate strength of the concrete and the yield point strength of the longitudinal reinforcement, including in the calculations the full gross area of the column. Spirals are not given consideration in computing the safe loads unless they are present in an amount sufficient to provide an increase in the ultimate strength of the core equal to, or greater than, the ultimate strength added by the shell surrounding the core. When present in this amount, the toughness, added by the spiral in event that the shell spalls or fails, is recognized by an increase in the safe load 25% over that for columns without this full amount of spiral.

Flat Slabs.—The section dealing with flat slabs has been somewhat expanded with respect to details incident to this type of construction, but has not been altered in the basic design requirements. Since no new test data have been available, the Committee has retained the principal limitations of the 1924 Report. The formulas for slab thickness have been simplified and so modified as to apply to concrete of any 28-day strength.

Two-Way Slabs.—For the design of two-way slabs, the Committee has adopted a method which recognizes the elastic plate action as a dominant factor in moment distribution and stress intensity. Considering the limitations of theory and the available test data, however, the Committee has placed principal emphasis on the simplicity of application.

Design Formulas.—The standard formulas for rectangular and T-beams and standard notations have become so widely recognized that they are omitted from the Report.

RECOMMENDED PRACTICE FOR THE USE OF CONCRETE AND REINFORCED CONCRETE

CHAPTER I—SCOPE AND DEFINITIONS

101—Scope

This report is intended to cover the use of concrete and reinforced concrete in general. In such structures as arches, tanks, reservoirs, chimneys, etc., where specialization relates principally to the mechanics of design and details of construction, the general provisions of the report may be applied with the modifications necessary to suit the special conditions.

102—Definitions

No attempt is made here to define all the terms current in concrete technology. Only those expressions which have particular application to the report and are not thoroughly established in the literature are included.

Anchorage—That portion of a reinforcing bar, and any attachment thereto, designed to resist pulling out or slipping of the bar when subjected to stress.

Bleeding—The escape of water from freshly placed concrete, commonly observed as an accumulation upon a horizontal surface.

Cantilever Retaining Wall—A reinforced concrete wall having a vertical section and a base, each of which resists by cantilever action the pressure to which it is subjected.

Buttressed Retaining Wall—A retaining wall with brackets or buttresses on the side opposite the pressure face uniting the upright section with the toe of the base.

Columns—A compression member, vertical or nearly vertical, the height of which exceeds three times its least lateral dimension.

Column Capital—In flat slab construction, the head or uppermost portion of a column or pilaster, designed and built to act as a unit with the column and the slab.

Column Strip—A portion of a flat slab or two-way panel embracing the area over the column, usually one-half panel in width, used for convenience in distributing the bending moments in the slab.

Combination Columns—A column in which a structural steel section, designed to carry the principal part of the load, is wrapped with wire and encased in concrete of such quality that some additional load may be allowed.

Composite Column—A reinforced concrete column with a core of structural steel or cast iron, in which the core is designed to carry a portion of the column load.

Consistency—A general term used to designate the relative mobility of freshly mixed concrete or mortar.

Counterforted Retaining Wall—A reinforced concrete wall with brackets or ribs on the pressure side of the vertical wall and designed to act with it in resisting overturning and sliding.

Creep—See Plastic Flow.

Deformed Bar—Reinforcement bar with projections, shoulders or lugs on the surface of the bar formed during rolling.

Diagonal Band—A group of reinforcing bars placed parallel to one of the diagonals of a panel in a flat slab reinforced in four directions.

Direct Band—A group of reinforcing bars placed parallel to the edge of a panel in a flat slab reinforced in four directions.

Drop Panel—The structural portion of a flat slab which increases the thickness of the slab in the area surrounding the column capital.

Effective Area of Reinforcement—The area obtained by multiplying the normal cross-sectional area of the reinforcement by the cosine of the angle between its direction and the direction for which the effectiveness is to be determined.

Effective Depth of Beam—The distance from the compression face to the centroid of the area of the tensile reinforcement.

Fineness Modulus—An empirical factor obtained by taking 1/100 of the sum of the percentages of a sample of aggregate retained on each of a specified series of sieves. The sieves used are Nos. 100, 50, 30, 16, 8, 4, ⅜-in., ¾-in., 1½-in., and larger, increasing in the ratio of 2 to 1.

Flat Slab—A concrete slab reinforced in two or more directions without beams or girders to transfer the loads to supporting columns.

Honeycomb—A surface or interior defect in a concrete mass characterized by the lack of mortar between the coarse aggregate particles.

Laitance—Extremely fine material of little or no hardness which may collect on the surface of freshly placed concrete or mortar, resulting from the use of excess mixing water.

Middle Strip—The middle portion of a flat slab or two-way panel, usually one-half panel in width, and symmetrical with respect to the center line of the panel, used for convenience in distributing the bending moments in the slab.

Modular Ratio—The ratio of the modulus of elasticity of steel to that of concrete.

Pedestal—A compression member, generally vertical, whose height does not exceed three times the least lateral dimension.

Pipe Column—A steel pipe filled with concrete.

Plastic Flow—The inelastic deformation in concrete resulting from the continued application of load.

Ratio of Reinforcement—The ratio of the effective area of the reinforcement to the effective area of the concrete at any section of a structural member.

Saturated and Surface Dry—A term used to describe the condition of an aggregate in which the pores of all the particles are completely filled with water, but their surfaces are free from moisture.

Slump—The shortening of a standard test mass of freshly mixed concrete, used as a measure of consistency in accordance with the standard method.

Strut—A compression member other than a column or pedestal.

Stiffness Factor—The value obtained by dividing the moment of inertia of a member by its length.

Vibration—A method of compacting concrete by mechanically producing wave motion of high frequency in the concrete.

CHAPTER II—MATERIALS

201—General

The recommendations of this committee covering the quality of materials —cements, admixtures, water, aggregates and reinforcing steel—are embodied in the accompanying specifications. The following comments indicate the basis and limitations of the specification requirements.

202—Cement

(*a*) In the case of normal portland cement and high early strength portland cement, reference is made to the current A. S. T. M. Specifications C 9–38 and C 74–39. No specifications are recommended for cements for various special purposes other than where high early strength is required. Although a number of specifications are now in use covering such special requirements as low heat of hydration, sulphate resistance, etc., the committee feels that it should refrain from sponsoring any specifications of this nature until they have received the endorsement of the American Society for Testing Materials, which is the affiliated body usually relied upon to sponsor national standards in this field. Until such standards are available, the Engineer should satisfy himself either by means of his own tests or by reference to reliable sources of information that the material which he proposes to use will adequately fulfill his special requirements.

(*b*) Specifications for special cements, when required, should be inserted in Sect. 203-S of the specifications.

203—Admixtures

(*a*) The committee considers that the benefits to be derived from the use in concrete of other than the essential ingredients (cement, aggregates, and water) depend so much upon the conditions surrounding the individual project that it is virtually impossible to write an adequate general specification for these materials. This applies particularly to admixtures which are employed for the purpose of promoting workability. The desirability of using an admixture as well as the amount to be used depends greatly on the characteristics of the essential ingredients, especially aggregate grading, as well as on the proportions in which they are to be combined. Before permitting the use of an admixture the Engineer should inform himself thoroughly as to the advantages or disadvantages to be derived from its use considering both quality and economy. He should determine definitely the effect of the proposed admixture on the strength, volume change, durability, and density of the concrete. The possibility of securing the desired results in other ways, such as by the use of additional cement, better aggregate gradation, closer water control during construction, etc., should be investigated. The committee recognizes that admixtures, under certain conditions, may impart desirable characteristics which cannot be secured as

economically by other methods. However, it should be emphasized that the use of admixtures cannot be considered a panacea for any of the ills which result from ignoring the fundamental principles governing the making of good concrete.

(*b*) Specifications for admixtures, when required, should be inserted in Sect. 204-S of the specifications.

204—Water

The mortar strength test is intended to assure the use of mixing water of satisfactory quality from the standpoint of concrete strength. The test may be waived in cases where the water to be used is of known satisfactory quality. Practical experience as well as results of laboratory investigations indicate, in general, that any water which can be safely used for drinking purposes will be satisfactory for use in concrete.

AGGREGATES

205—General

In preparing its aggregate specifications the committee has utilized, insofar as possible, the specifications of the Federal Government and the existing standards of such specification writing bodies as the American Society for Testing Materials, the American Association of State Highway Officials, and the American Railway Engineering Association. Attention is directed particularly to the fact that in the case of many of the requirements for quality two test limits are shown, a recommended limit and an outside permissible limit. This arrangement is in recognition of the fact that specifications for such locally occurring materials as aggregates must be based, to a certain extent, upon the available material. The recommended limit should be specified in all cases where it is economically practicable to secure materials conforming thereto. When it is considered necessary to use aggregates not meeting the recommended limits, less restrictive limits may be specified, but this fact should be recognized in the design of the concrete mixture and in the control of the concrete during construction. In no case should limits beyond the maximum permissible values indicated be specified.

206—Fine Aggregate Grading

Attention is called to the fact that the relatively wide range in grading which is shown in Sect. 208-S should be permitted only when it is economically impracticable to obtain materials meeting more restrictive requirements. The most desirable grading will depend upon the type of work and class of concrete. For the leaner mixes, or when a small size coarse aggregate is used, in cases where the degree of workability is important, it is desirable to further restrict the allowable ranges in sizes shown in Sect. 208-S so as to insure a grading approaching the maximum percentage passing each sieve. On the other hand, for the richer mixes, in the interest of maximum strength and economy, a grading as coarse as is consistent with the requirements for

workability should be specified. However, in no case should a range in grading be specified more restrictive than indicated below:

Passing No. 16 sieve—range 20% or less
Passing No. 50 sieve—range 15% or less
Passing No. 100 sieve—range 5% or less

207—Coarse Aggregate Grading

The requirements for size of coarse aggregate specified in Sect. 215-S are those recommended by the Joint Technical Committee of the mineral aggregates associations. They have been adopted for use in certain Federal specifications and by the American Association of State Highway Officials and as Simplified Practice Recommendation R 163–39 of the Division of Simplified Practice of the Department of Commerce. The sizes seem to cover adequately the usual requirements for concrete. The grading limitations also are believed to be reasonable from the standpoint of both producer and consumer. The committee recommends that these sizes, with the corresponding grading limits, be used wherever it is practicable to do so.

208—Deleterious Substances

The requirements covering deleterious substances as given in Sect. 210-S and 216-S are, of necessity, quite general. Broadly speaking, the term "deleterious substances," as applied to aggregates, includes any material contained therein which will adversely affect the quality of the concrete in any way. This would include a great variety of materials such as shale, unsound chert, coal, ochre, excessively flat or elongated fragments, etc., coatings of various kinds which would affect the bond, and materials which would adversely affect the hardening of the cement. Except for certain general limits which are recognized in most specifications, reliance must be placed upon the judgment of the Engineer based on past experience with the types of material which will be encountered and with due regard to the economic considerations involved. With these considerations in mind, the Engineer should list in Sect. 210-S and 216-S the additional deleterious substances which in his judgment should be controlled, together with appropriate limits, based wherever possible upon recognized test procedures, reference to which should be made in Sect. 229-S.

209—Soundness

When the concrete is to be exposed to the weather and other destructive agencies, care should be exercised to select aggregates of durability adequate for the degree of exposure. As indicated in Sect. 213-S and 217-S of the specifications, principal reliance should be placed on service records, when adequate information in that regard is available. In the absence of such information, the accelerated soundness test specified in Sect. 213-S and 217-S should be utilized. Methods for accelerated soundness tests involving controlled freezing and thawing in the laboratory and the use of salts,

principally magnesium sulphate ($MgSO_4$) and sodium sulphate (Na_2SO_4), to simulate freezing and thawing, have been used. The committee has suggested the accelerated soundness test using sodium sulphate (Na_2SO_4) and has recommended requirements based on a relatively limited amount of information resulting principally from experience in climates where considerable freezing and thawing are encountered.

210—Lightweight Aggregates

Comparatively limited experience in the field of lightweight aggregates justifies a more conservative specification at the present time than may be desirable later, particularly in those cases where exposure to wear and to weather are not major factors. Therefore, practically no concession is made for this type of aggregate in the general aggregate requirements other than that of lower compressive strength in the mortar strength test. It is suggested, however, that coarse aggregate weighing less than normal aggregates and more than 55 lb per cu ft (recommended as the maximum weight for lightweight aggregates), and meeting all requirements for lightweight aggregates except weight, may be used where light-weight concrete is permissible when in the opinion of the Engineer the weight requirement may be waived.

211—Aggregates—Fireproofing

(*a*) Coarse aggregates for use in fireproofing have been divided into two classifications in recognition of differences in behavior when subjected to high temperatures. In general, Group 1 includes aggregates predominating in materials which change in volume a relatively small amount when exposed to high temperatures, and cinders low in combustible materials; Group 2 includes aggregates containing substantial proportions of particles which change in volume a relatively large amount when exposed to high temperatures, and cinders containing combustible material in excess of the desirable minimum.

(*b*) The dividing line between the two groups is, necessarily, somewhat arbitrary, but it is believed that it has been drawn as accurately as available data permit. That there is a difference in the ability of concrete made with different aggregates to resist high temperatures is evident from information available; how important these differences are to the protection of life and property is not so readily evaluated. It should be emphasized that adequate fireproofing can be obtained with the materials in either group so long as the differences in their characteristics are taken into account in the design of the concrete.

(*c*) The classification of the different types of aggregates is consistent with that in the "Recommended Minimum Requirements for Fire Resistance in Buildings" outlined in the Report of the Department of Commerce Building Code Committee, although the limitation on percentage of siliceous particles is more rigid. The committee believes that the recommendations outlined in Sect. 225-S, when considered in connection with

those in Sect. 505, offer a conservative basis for the selection of coarse aggregates for fireproofing.

212—Resistance to Abrasion

Typical requirements covering wear resistance of coarse aggregates for use in concrete subject to surface abrasion are included. There are no generally recognized tests for measuring the hardness or abrasive resistance of fine aggregates. The committee recognizes that, under certain circumstances, fine aggregates possessing high resistance to wear are essential and recommends that, in such cases, the general clause covering fine aggregates (Sect. 207-S) be amplified by the Engineer to include a description of the desired characteristics.

Metal Reinforcement

213—General

(*a*) The principal requirements in the selection of metal reinforcement are the yield point, the bond value, and the ductility.

(*b*) The advantage of high yield point steel has been recognized for many years, and is self-evident in view of the fact that the yield point of the reinforcement practically determines the ultimate strength of both flexural and compression members.

(*c*) In ordinary commercial grades of steel, a high yield point is generally accompanied by a decrease in ductility. The balance, therefore, between a high yield point and satisfactory ductility has developed the difference of opinion that exists as to the grade of steel to be used. The relative importance of these qualities depends on the character and service conditions of the structure. The choice of the grade of steel, therefore, becomes a matter of engineering judgment.

214—Bond

The tendency toward increase in unit stresses and the use of high strength concrete emphasizes the need for higher and more dependable bond resistance than that obtained by the use of plain bars. In the absence of standard specifications for acceptable types of deformed bars it has been the practice to permit an increase of 25% in bond value of deformed over that of plain bars. This increase in bond resistance to be useful should be developed at very small values of end slip in pull-out tests.

215—Ductility

The necessary ductility in metal reinforcement is that which permits fabrication by cold-bending without indication of fracture or reduction in tensile strength. The practical test for ductility is the cold-bend test in the various specifications. Material that complies fully with the bend test is sufficiently ductile for fabrication purposes.

216—Recommended Sizes

The following standard sizes listed in the U. S. Department of Commerce Simplified Practice Recommendation R26–30, are recommended:

Sizes	Area (sq in.)	Weight (lb per ft)
1/4″ round	0.05	0.167
3/8″ round	0.11	0.376
1/2″ round	0.20	0.668
1/2″ square	0.25	0.850
5/8″ round	0.31	1.043
3/4″ round	0.44	1.502
7/8″ round	0.60	2.044
1″ round	0.79	2.670
1″ square	1.00	3.400
1 1/8″ square	1.27	4.303
1 1/4″ square	1.56	5.313

CHAPTER III—PROPORTIONING, MIXING, CURING, AND TESTING CONCRETE

301—General

The recommendations of this committee, covering proportioning, mixing, curing, and testing concrete, are embodied in the succeeding paragraphs and in the accompanying specifications.

302—Basis for Specification

(*a*) There are two distinct views with respect to the function of the Contractor which cannot be reconciled in a single specification. Under one of these it is assumed that the function of the Contractor is to contribute his skill as a concrete technician as well as his ability in handling construction equipment and materials. Under the other it is assumed that the Contractor's function is purely that of a builder and that the Engineer, who prepares the plans and specifications, is the concrete technician. Obviously, the manner of specifying the quality of the concrete and how it shall be controlled will not be the same under these two assumptions. The committee, therefore, presents alternate specifications covering the sections on proportioning and concrete quality.

(*b*) Under Alternate A the Engineer establishes the general limitations of strength and water content within which the Contractor is permitted considerable latitude in the choice of materials and the methods of handling them. The Contractor is required to produce a plastic and workable concrete of the required strength and water content that can be placed without segregation or honeycomb. Under this Alternate the Contractor assumes the responsibility for the quality. If the concrete is lacking with respect to any of the above qualities, he must make good the deficiency at his own expense.

(*c*) Under Alternate B the Engineer designates in detail the quantities of material to be used, the length of mixing time, amount of water, range in slump, etc., and to this extent is responsible for the quality of the concrete. Changes in quantities or types of materials can be made only on the order of the Engineer and then adjustment of compensation will be required under the clauses covering extra compensation or credit in the contract. The Engineer, on behalf of the owner, is responsible for the adequacy of the specification.

(*d*) In using the accompanying specification, the Engineer must designate which of the Alternates is to be used, and fill in the necessary tables with the specific information required for the project. The recommendations of the Committee bearing on the points involved will be found in the succeeding paragraphs.

303—Requirements of Concrete for Various Conditions of Exposure

(*a*) Since the publication of the 1924 report there has been considerable development in the technology of concrete in which special emphasis has been placed on properties other than compressive strength, particularly durability and watertightness. These properties, it has been shown, are controlled principally by the same factors which control compressive strength; namely (for aggregates and cement of given quality) by the relative proportions of cement and water and the extent to which adequate curing is provided. Studies have also shown that for durability, concrete when finally in place must be free from any honeycomb or other defects which permit the entrance of water. The recommendations of this committee, therefore, are built around the control of the water content and curing and those factors which influence workability of the concrete and the methods of placing and compacting.

(*b*) In Table 1 are given recommended water contents which are suitable for concrete intended for various conditions of exposure. These are based on the assumption that the concrete will be plastic and workable, and placed and compacted in such manner that a dense, homogeneous mass will be obtained. They also presume that the concrete will be sufficiently protected from loss of moisture and from low temperatures to insure that proper hardening will develop.

304—Specified Strengths and Water Contents—Alternate A

(*a*) Alternate A is based on a dual control in which both a minimum strength and a maximum allowable water content are specified. It puts on the Contractor full responsibility for the strength, consistency, and water-cement ratio. The strengths to be inserted in Table A, Sect. 301-SA of the specifications, are intended to be those meeting the requirements of the design calculations. As required in the specifications (Sect. 302-SA) the Contractor must submit mixtures which he proposes to use for the different classes of work together with a laboratory report showing that these mixtures will produce the strengths specified and do not exceed the maximum allowable water contents. The method of making the tests and the range of mixtures are covered by the specification.

(*b*) The maximum allowable water contents to be inserted in Table A, are those meeting the exposure requirements which in the judgment of the Engineer will be required for the several portions of the work. The values to be inserted in Table A, Sect. 301-SA, can be obtained from Table 1. It may frequently happen that the water content which will meet the particular exposure requirements will correspond to a strength of concrete in excess of that upon which the design calculations were based. Likewise, it may be found that to meet the strength requirements will require a water content even lower than that needed for the exposure.

(*c*) To avoid a multiplicity of concrete mixes on a given project, a series of mixes, such as shown in Table 2, is recommended. The 8 mixes shown provide for the entire range of exposures covered in Table 1. The strengths

TABLE 1.—WATER CONTENTS SUITABLE FOR VARIOUS CONDITIONS OF EXPOSURE (GAL PER SACK OF CEMENT)

Type or Location of Structure	Severe or Moderate Climate, Wide Range of Temperatures, Rain and Long Freezing Spells or Frequent Freezing and Thawing					Mild Climate, Rain or Semi-Arid, Rarely Snow or Frost				
	Thin Sections		Moderate Sections		Heavy and Mass Sections	Thin Sections		Moderate Sections		Heavy and Mass Sections
	Reinf.	Plain	Reinf.	Plain		Reinf.	Plain	Reinf.	Plain	
A. At the waterline in hydraulic or waterfront structures or portions of such structures where complete saturation or intermittent saturation is possible, but not where the structure is continuously submerged: In sea water In fresh water	5 5½	5½ 6		6 6½		5 5½	5½ 6		6 6½	
B. Portions of hydraulic or waterfront structures some distance from the waterline, but subject to frequent wetting: By sea water By fresh water	5½ 6	6 6½		6 6½		5½ 6	6½ 7		7 7½	
C. Ordinary exposed structures, buildings and portions of bridges not coming under above groups	6	6½		7		6	7		7½	
D. Complete continuous submergence: In sea water In fresh water	6 6½	6½ 7		7 7½		6 6½	6½ 7		7 7½	
E. Concrete deposited through water	[a]	[a]	5½	5½		[a]	[a]	5½	5½	
F. Pavement slabs directly on ground: Wearing slabs Base slabs	5½ 6½	6 7	[a] [a]	[a] [a]		6 7	6½ 7½	[a] [a]	[a] [a]	

G. Special cases:
(a) For concrete exposed to strong sulfate ground waters, or other corrosive liquids or salts, the maximum water content should not exceed 5 gal per sack. See Sect. 609.
(b) For concrete not exposed to the weather, such as the interior of buildings and portions of structures entirely below ground, no exposure hazard is involved and the water content should be selected on the basis of the strength and workability requirements.

[a] These sections not practicable for the purpose indicated.

shown for the different water contents represent those now commonly obtained with normal portland cement. For important work it is recommended that a similar table be drawn up based on tests of the materials available for the project. Such tests should be carried out as specified in Sect. 321-S to 325-S.

TABLE 2.—RECOMMENDED MIXES

Class of Concrete	Maximum Allowable Net Water Content (gal per sack of cement)	Probable Minimum Allowable Compressive Strength at 28 Days (lb per sq in.)
(Appropriate class designation to be inserted)	5	5,000
	5½	4,500
	6	4,000
	6½	3,600
	7	3,200
	7½	2,800
	8	2,500
	8½	2,000

305—Specified Mixtures—Alternate B

(*a*) Alternate B is a specification based primarily on a designated cement content, but in which there is also specified a maximum water content, a maximum size of aggregate, a range in slump, and a range in percentage of fine aggregate. The other items to be filled in Table B (Sect. 301-SB) are purely informative and not to be confused with specified values. It is strongly recommended that the Engineer, whenever practicable, make preliminary tests of available materials in order to determine the values to be inserted in Table B, Sect. 303-SB.

(*b*) Where it is impracticable to make preliminary tests, and a specification along the lines of Alternate B is to be adopted, the mixes in Table 3 are suggested. The values in Table 3 are for a concrete of a medium consistency (4-in. slump). The quantities of cement indicated will need to be changed if other consistencies are to be entered in Table B. Since the quantities in Table 3 are all approximate, it will be sufficiently accurate to modify the cement content in accordance with the following: For each 1-in. difference in slump, change the cement factor ⅛ sack per cu yd, increasing this factor for slumps greater than 4 in. and reducing it for slumps less than 4 in.

(*c*) When tests are being made to determine the quantities and proportions of materials to use in Table B, the weights specified in columns 8 and 9 should be based on the known specific gravities of the aggregates to be used. When these data are supplied from Table 3, it should be recognized that the approximate quantities given in columns 6, 7, and 8 are based on bulk specific gravity of 2.65 in a saturated and surface-dry condition. For aggregates of different specific gravities the approximate weights should be multiplied by the ratio of actual specific gravity to the assumed value of 2.65.

(*d*) It should be pointed out further that in the use of Alternate B the various classes of concrete are determined either by tests or by selection

from data such as are given in Table 3. Where the tests are to be made the Engineer will arrive at his own values of strengths for various water contents and should select his concrete classes accordingly. Where Table B in the specification is to be filled out from Table 3, it must be understood that the

TABLE 3.—APPROXIMATE QUANTITIES

Max. Size Coarse Agg. (in.)	Estimated 28-Day Comp. Str. (lb per sq in.)	Cement Factor, Sacks Cement per cu yd Freshly Mixed Concrete	Max. Water per Sack Cement (gal)	Fine Agg. % Total Agg. (See Note A Below)	Approx. Wts. Saturated Surface-Dry Agg. per Sack of Cement (lb) (See Note B Below)		
					Total	Fine Agg.	Coarse Agg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	2,250	4.9	8	40–46	660	280	380
2	2,250	4.5	8	37–43	740	300	440
3	2,250	4.1	8	34–40	840	310	530
1	2,750	5.6	7	39–45	570	240	330
2	2,750	5.1	7	36–42	640	250	390
3	2,750	4.7	7	33–39	720	260	460
1	3,000	6.0	6½	38–44	520	210	310
2	3,000	5.5	6½	36–42	590	230	360
3	3,000	5.1	6½	34–40	660	240	420
1	3,300	6.5	6	37–43	470	190	280
2	3,300	6.0	6	35–41	530	200	330
3	3,300	5.5	6	33–39	600	220	380
1	3,700	7.2	5½	36–42	420	160	260
2	3,700	6.7	5½	34–40	470	170	300
3	3,700	6.2	5½	32–38	530	180	350
1	4,250	8.0	5	35–41	370	140	230
2	4,250	7.4	5	33–39	420	150	270
3	4,250	6.8	5	31–37	470	160	310

NOTE A—The limits shown in Col. (5) are approximate and percentages falling outside of the limits shown may frequently be found necessary to produce concrete of the desired workability. When expressed in terms of absolute volume they are applicable to aggregates of different specific gravities; when expressed in terms of weight, differences in specific gravity should be taken into account.

NOTE B—The approximate weights in columns (6), (7), and (8) are based on a bulk specific gravity of 2.65 in a saturated surface-dry condition.

strengths indicated are based on normal portland cement and aggregates meeting the requirements of these specifications determined in a manner specified in Sect. 321-S to 325-S. If other than normal portland cement is to be used, these values will not apply.

(*e*) Particular attention is called to the differences between Table 3 and Table 2. The latter is intended for use where the Contractor has assumed full responsibility for the quality of the concrete and where regular tests will be made to assure that the intended strengths are secured. Table 3, on the other hand, is compiled merely as suggested values to be used when actual data for the materials at hand are lacking. Because of this, the strength values indicated for the different water contents are purposely made conservative.

306—Use of High Early Strength Portland Cement

Both Alternates A and B carry provisions for the use of high early strength cement (309-SA and 306-SB). These are based on the assumption that the 3-day and 7-day strengths for the high early strength cement concrete are equivalent, respectively, to the 7-day and 28-day strengths for the normal portland cement concrete. When the materials to be used show other relationships, these of course should be specified.

307—Consistency and Size of Aggregate

(*a*) The consistency of the concrete and the maximum size of aggregate to be used will be dependent upon the conditions prevailing at each individual job. The factors which will govern are: The available materials, size of the member, quality of concrete to be produced, arrangement of reinforcement, and the manner of transporting and placing the concrete. Decision in respect to these items should be made with the requirements of plasticity and workability clearly in mind. In structures, where the exposure will be severe, it is of utmost importance that the plasticity and workability of the concrete be such that it can be placed and compacted without honeycomb or other defects which will permit the entrance of water.

(*b*) Table 4 gives suggested aggregate sizes and consistencies suitable for several different classes of work. See Sect. 504–506 and 854 for recommendations regarding embedment and spacing of reinforcement.

TABLE 4.—SUGGESTED AGGREGATE SIZES AND CONSISTENCIES

Portion of Structure	Consistency-Slump		Maximum Size of Coarse Aggregate (in.)
	Maximum (in.)	Minimum (in.)	
Reinforced foundation walls and footings	5	2	1½
Plain footings, caissons and sub-structure walls	4	1	2
Slabs, beams, and reinforced walls	6	3	1
Building columns	6	3	1
Pavements	3	2	2
Heavy mass construction	3	1	3 to 6[a]

[a] In making the slump test, all aggregate larger than 2 inches should be screened out of the mixture.

(*c*) When high frequency mechanical vibration is used for compacting concrete, the limiting consistencies in Table 4 will need to be modified. When properly applied, mechanical vibration permits the use of stiffer consistencies than are possible under hand placing. For a given water content, therefore, leaner mixtures, that is, lower cement factors, can be utilized when this method of placing is employed. Generally, the ratio of fine to coarse aggregate should be reduced where high frequency mechanical vibration is employed. See Sect. 404 for Recommended Practice on Placing Concrete by Vibration.

308—Ready-Mixed Concrete

(*a*) Sect. 313-S and 315-S require that the maximum size of batch which may be placed in a truck mixer or agitator shall be in accordance with the "specified rating." In general, the manufacturer's rating should be used, since it takes into account the strength and balance of the entire mechanism as well as its efficiency as a mixer or agitator. However, experience with equipment now in general use shows that the rated capacities should not exceed the following percentages of the gross volume of the drum:

Description	Percentage
1. Truck mixers performing the entire mixing operation (see Sect. 313-S)	
(a) Top-door loading	50
(b) End-door loading	57½
2. Truck mixers completing the mixing of concrete partially mixed at central plant (see Sect. 314-S)	66⅔
3. Agitators or truck mixers used for transporting mixed concrete (see Sect. 315-S)	80

Frequently, the manufacturer's ratings are less than the limits given above because of factors other than mixing efficiency.

(*b*) In Sect. 315-S, a period of 1½ hr within which delivery of ready-mixed concrete must normally be made is specified. This is based on the results of research which have shown that a period of 1½ hr between the beginning of mixing and the completion of the discharge of the batch results in no detrimental effects on the concrete. The data indicate that under specially favorable conditions periods up to 2 and 3 hr may be allowed. Experience has shown that with certain soft aggregate greatly prolonged mixing will result in a decrease in size of aggregate particles and a corresponding increase in the proportion of fine material. When air temperatures are unusually high, or the ingredients of the concrete mixture are such that an unusually quick time of set or loss of plasticity may occur, it may be necessary to specify periods shorter than 1½ hr to insure that no damage be done to the concrete. The exact period will depend upon the materials being used and the prevailing temperatures. It is unlikely, except under the most unusual circumstances, that it will be necessary to specify a period of less than 1 hr.

309—Curing

(*a*) The protection of concrete against low temperatures and loss of moisture during the period immediately after placing is an important factor in the development of both strength and durability in concrete. Sect. 318-S in the specifications requires that the concrete be protected to prevent loss of moisture from the surface and to prevent temperatures at the surface from going below 50° F for periods of 7 days where normal portland cement is used, and 3 days where high early strength portland cement is used. In fixing these limits it is recognized that under average conditions, curing of concrete does not cease immediately upon removal of the protection against loss of moisture. Where the conditions are severe, as, for example, thin

sections in hot dry air or low temperatures, it may be desirable to increase somewhat the protection periods specified.

(*b*) The committee recognizes that under the specification requirement in Sect. 318-S some doubt may arise as to the methods which will be acceptable. It is not prepared, however, to offer more specific recommendations, but it does suggest the following methods which have been used to achieve the desired end with varying degrees of success:

(1) Surface remaining in contact with the forms;
(2) The surfaces of slabs protected by ponding;
(3) Covering with burlap or cotton mats kept continuously wet;
(4) Covering with paper of suitable type;
(5) Covering with one-inch layer of thoroughly wet sand, earth, or sawdust;
(6) Covering with six-inch layer (loose) of thoroughly wet straw, hay, or similar material; and,
(7) Continuous sprinkling of the exposed surfaces.

(The committee also calls attention to the specifications for curing portland cement concrete adopted by the A. R. E. A. in March, 1936, which carry very definite requirements for protection against low temperatures and loss of moisture. These specifications are reproduced in Appendix 4.)

310—Field Tests

(*a*) The sections in the specifications referring to field tests (320-S to 325-S) are intended primarily for use with Alternate A under which the Contractor assumes responsibility for the strength of concrete being produced. While the tests are to be made at the expense of the owner and entirely under the supervision of the Engineer, the clauses are included in the specification so that there will be a definite understanding as to the methods by which the quality of the concrete being produced is to be judged.

(*b*) Where a specification along the lines of Alternate B is used such explicit directions for making the tests are not necessary. However, there seems to be no good reason for omitting these detailed clauses in such case.

311—Field-Cured Specimens

(*a*) The question may arise as to why the specifications for Field Tests of Concrete (Sect. 320-S to 325-S) call for the curing of specimens in the laboratory, rather than in the field. The committee takes the position that under the conditions prevailing in most structures it is practically impossible to store specimens in the field in such a manner that their strength can be assumed to represent accurately the strength of the concrete in the structure. An exception is noted in the case of pavement slabs in which a procedure, described in (*d*) below, is used that gives reliable indications as to the strength of the concrete.

(*b*) Under such a specification as Alternate A, the quality of concrete being placed in the usual type of structure can only be judged on the basis of specimens stored in accordance with standard laboratory procedure.

(*c*) Field-cured specimens may give information of value as to the curing conditions prevailing on the job, but the results must be interpreted with caution, and under no circumstances should they be used to determine compliance with the requirements of a strength specification of the type covered by Alternate A.

(*d*) As noted above, it is quite common practice in the construction of concrete pavements to use the results of tests of field-cured beam specimens to determine the age at which it will be safe to open the road to traffic. The usual practice is as follows: After removal from the molds at the end of 24 hr the specimens are bedded on the subgrade alongside the pavement and the sides banked with earth, leaving only the surfaces exposed. Every care is taken to give the surfaces of these beams exactly the same curing treatment as the pavement. A sufficient number of specimens is made each day to permit testing at various ages until the results show that the concrete has attained the required flexural strength. The tests are ordinarily made on the job, using one of the several types of portable beam testing machines on the market.

312—Enforcement of Strength Requirements

Any contract in which concrete of a definite strength is specified should contain some provision outlining the procedure to be followed in case it is discovered after portions of the structure are completed that the concrete fails to comply with the requirements. The objection to a strength specification has largely been based on the absence of such provisions. Sect. 326-SA to 328-SA in the specifications are intended to cover this contingency. These sections should be stricken out if Alternate B Specification is adopted.

CHAPTER IV—FORMS AND PLACING

401—General

Except for the following special cases the recommendations of the committee are embodied in the specifications.

402—Pneumatic Placing of Concrete

(*a*) In order to obtain the best results with equipment now available the following general rules should be observed:

(1) The placing equipment should be located as close to the point of deposit as practicable, and the concrete should be conveyed from the mixer with as little segregation as conditions will permit.

(2) The volume of concrete at each discharge of the gun, in general, should not exceed 7 cu ft. Distances from gun to nozzle greater than 1000 ft should be avoided. The general slope of the discharge line may vary from a horizontal to a vertical direction, but in no case should it be inclined downward.

(3) The position of the nozzle should be such that the concrete is directed to the point of deposit without impinging directly on the reinforcement, and without excessive rebound of material.

(4) Concrete of a medium consistency gives the best results. Sloppy mixes are unsatisfactory.

(*b*) When this method is being used cores should be drilled at appropriate intervals for tests to determine whether the concrete being placed is of the desired quality.

403—Pumping Concrete

(*a*) The pumping equipment, the charging hopper, and the devices used at the outlet of the pipe should be such that concrete of the specified quality and consistency can be transported and delivered in the forms without segregation. The devices used at the outlet of the pipe—deflectors, spouts, hose connections, swivel-mounted elbows, elephant trunks, etc.,—should be selected to meet the particular requirements of the job.

(*b*) The pump should be able to produce a working pressure of at least 300 lb per sq in., and the pipe line and fittings should be designed to resist approximately double this pressure.

(*c*) The pipe line should be laid with as few bends as possible, and changes in direction should be accomplished preferably with bends 45° or less. Ninety degree bends should be used only where they are unavoidable.

(*d*) Where it is necessary to lay the pipe with a downhill grade, a choke should be used at the discharge end to keep a continuous flow of concrete in the line. For vertical pumping, a shut-off valve should be placed in the lower line to prevent backflow when pumping is stopped, or when making pipe changes or cleaning at the end of a run.

(*e*) Concrete having a slump of 2 in. or more can be handled easily by pumping—irrespective of the character and type of coarse aggregate, that is, whether round or angular. For workable mixes of less than 2-in. slump, gravel concrete pumps more easily than crushed stone concrete. With concrete having 4.5 sacks or less cement per cubic yard the quality and grading of sand is important for successful pumping. For such concrete, sand with a relatively high per cent of fines that will hold water and prevent "bleeding" is desirable.

(*f*) A shut-down of half an hour usually will not prevent the starting of the pump and the delivery of the concrete in good condition. The permissible limit of a shut-down with a full charge of concrete in the line will depend on temperature conditions and the rate of stiffening or hardening of the concrete.

(*g*) Immediately before concreting is begun the empty pipe line should be flushed with water and a charge of thin grout placed ahead of the concrete to lubricate the line properly. About 1 cu ft of grout should be used for each 1000 sq ft of inside surface area of pipe line and a plug or "go-devil" should be used just ahead of the grout to force out any free water.

(*h*) At the end of a run a "go-devil" should be forced through the pipe line to clean out the concrete.

(*i*) Job experience with pumping equipment suggests the use of the following sizes of pipe, maximum sizes of coarse aggregate, and slump of concrete for maximum pumping distances.

Pipe Size (in.)	Slump of Concrete (in.)	Maximum Pumping Distance—ft		Maximum Size Material (Passing Screen Size—in.)
		Horizontal[a]	Vertical[b]	
8	Not less than 1	1000	100	3
7	Not less than 1	800	100	2½
6	Not less than 3	600	100	2

[a] A 90° elbow is estimated to be equivalent to 40 ft of horizontal piping.
[b] Not over 200 ft of pipe, actual.

404—Placing by Vibration

(*a*) The use of vibration for compacting and placing concrete is comparatively new, and differences of opinion exist as to the best methods, particularly as to frequency,[4] methods and position of application, amplitude,[1] length of time of vibration, force of blow (related to the size of vibrator), and the area or volume of concrete over and through which vibration is effective. It is desirable, therefore, that the supervising personnel, as well as the operators of the vibrating equipment, be experienced.

[4] See definitions in Chapter I.

(*b*) Vibration imparts no new properties to concrete. However, its use permits economies or improvement in the quality of the concrete through the use of stiffer and harsher mixtures with lower water content than is possible with the usual methods of placement. The consistency of the concrete should be adjusted to the particular conditions of placement and equipment in use. The concrete should not be so dry as to make placement difficult, nor so wet as to produce a fluid condition on the surface of the concrete. In general, vibration should not be used when the slump of concrete exceeds 3 in. except as an aid in placing under difficult conditions.

(*c*) All jobs on which the use of vibration is new should start with a mixture which can be placed readily by the usual methods. The quantity of cement, water, and proportion of fine to coarse aggregate should then be adjusted gradually until the mixture has the desired placeability. This will generally require a readjustment in the ratio of fine to coarse aggregate, usually an increase in the percentage of coarse aggregate. Where economy is desired the total volume of the aggregates should be increased. Where improved quality is desired, the water-cement ratio should be reduced.

(*d*) Where excessive bleeding occurs which cannot be readily corrected by adjusting the mixture, the percentage of sand finer than the No. 50 sieve should be increased.

(*e*) Vibration should not be applied directly or through the reinforcement to sections or layers of concrete which have hardened to the degree that the concrete ceases to become plastic under vibration. Vibration should not be continued at any one point to the extent that localized areas of grout are formed.

(*f*) One of the evidences of sufficient vibration is the appearance of a line of cement paste at the junction of the concrete and the forms, or the concrete and surface of the steel reinforcement. When the decrease in volume of the concrete is no longer apparent the vibration has been sufficient.

(*g*) Vibration should not be used to make concrete flow in the forms over distances so great as to cause segregation.

(*h*) Vibration is applied to the concrete in various ways, depending upon the type and size of member being cast and whether applied in the field or in the shop. It is applied to the forms generally for sections of walls, columns, floor slabs, and precast units too small for operating vibrators of the internal type. Both internal vibrators and platform vibrators are used for compacting concrete in massive structures. A table vibrator is used for making cast stone or concrete products. For pavement work a vibrating screed is used.

(*i*) Vibration increases pressure on the forms which should therefore be designed for the higher pressures and greater strains on ties and supports. Proper precautions should be taken to prevent leakage of mortar through joints in the form work during vibration.

405—Number and Size of Vibrators Required

(*a*) The factors which govern the selection of type, number, and size of vibrators are the following: Depth and area of section; size of batch; number of batches per hour; size of aggregate; amount and spacing of reinforcement; and proportions, particularly the respective amounts of fine and coarse aggregate and the consistencies of the mixtures.

(*b*) The number and size of vibrators of whatever type used should be such as to insure vibration throughout the entire volume of concrete to be vibrated. Application of vibrators should be at points uniformly spaced and not farther apart than the radius over which vibration is visibly effective. The vibration should be such that the concrete becomes uniformly plastic.

406—Pneumatically Applied Mortar

(*a*) Construction utilizing pneumatically applied mortar has been in the hands of a few organizations specializing in this field and utilizing equipment produced by a very limited number of manufacturers. The type of construction has been in use for many years and considerable advance in technique and equipment has been made during that period, but there is still considerable divergence in procedure between the different users. The purpose of this section is to provide a resumé of accepted practice as supplementary to the general specifications.

(*b*) The results obtained in pneumatically applying mortar depend to a large extent on the skill of the operator and the work should be done only by experienced men.

(*c*) Two types of equipment are available, single or double chamber. The single chamber type is operated intermittently, and is adaptable to small jobs only. The double chamber type which can be operated continuously is the most common type in use.

(*d*) The grading of the sand is important in obtaining high strength and density. The sand should be passed through a 3/8-in. sieve and have a fineness modulus of 3.0 or less. Stone sand subject to the same grading limitations as natural sand gives satisfactory results.

(*e*) The proportions of cement to sand for various purposes should range from 1 part cement to 3 parts sand to 1 part cement to 4½ parts sand, in terms of dry and loose volumes. The mortar in place will have a somewhat lower proportion of sand because of the loss due to rebound.

(*f*) Control of the water content is important for pneumatically placed mortar in order to obtain proper placement. The water content should be such that a very slight film of water will form on the surface of the applied material. Insufficient water results in dry porous spots and excess water causes low strength and slipping of the mortar.

(*g*) The air and water pressure should be maintained uniform. The water pressure should be at least 15 lb per sq in. higher than the air pressure which should be sufficient to give proper velocity to the material leaving the nozzle. To avoid excessive impact the air pressure should not exceed 75 lb per sq in.

(*h*) The sand should be neither excessively dry nor wet—about 4 per cent moisture by weight is desirable. Sand and cement should be thoroughly premixed by machine as very little mixing takes place during the application.

(*i*) The velocity of the material that leaves the nozzle should be maintained uniform and should be such as to produce a minimum of rebound of the sand. The nozzle should be held between 3 and 4 ft from the surface being covered and should be kept moving to obtain a uniform coating.

(*j*) Special care should be taken in the removal of forms and in the curing to avoid cracking of the thin sections. Placing at temperatures below 50° should not be attempted unless adequate facilities are available for keeping the mortar above 50° during and after placing. The surface to which mortar is applied should be free from frost.

(*k*) Shooting strips should be used at corners, edges, and on surfaces where necessary to obtain true lines and proper thickness. The surface of the mortar may be "steel floated" when a very smooth finish is desired.

(*l*) The placement equipment should be thoroughly cleaned whenever work is to be stopped for a period in excess of thirty minutes.

(*m*) The position and size of reinforcement, where required, and the thickness of coating vary with the use of the pneumatically applied mortar and should be within the limitations given below. Square reinforcement bars should not be used.

Use	Reinforcement	Thickness
Encasement of Steel	Galvanized welded fabric 2 × 2—No. 12 and No. 12 or 3 × 3—No. 10 and No. 10 bent to templet, and securely fastened to the steel at ¾ in. from steel.	1½ in. to 2 in. placed in two layers, second ⅛ in. thick.
Floor, Wall, and Roof Slabs	Rods and galvanized welded fabric not larger than ⅜ in. diameter sufficient for load requirements. Reinforcement not closer than ¾ in. to exposed surface.	As determined by load requirements. Placed in two or more layers. Final coat ⅛ in. thick.
Stucco or Facing on Tile, Terra Cotta, Brick, and Concrete	Not necessary except for badly disintegrated surfaces in which case use galvanized welded fabric equal to 0.2% of cross-sectional area of the mortar securely attached to the structure and located at middle of coating.	⅝ in. to 1 in. placed in two layers, second ⅛ in. thick. Screed to proper surface before applying second layer.
Concrete Restoration	Galvanized welded fabric 2 × 2—No. 12 and No. 12 or 3 × 3—No. 10 and No. 10 securely attached to old structure at middle of coating. Two layers of mesh for thickness of 3 in. and greater.	Not less than 1 in. placed in two or more layers. Screed to proper surface before applying final ¼ in. layer.
Linings for Reservoirs	Galvanized welded fabric 4 × 4—No. 8 and No. 8 or greater at middle of coating.	Not less than 2 in. in two or more layers.
Linings for Canals and Ditches	Galvanized welded fabric not less than 0.2% of cross-sectional area of mortar middle of slab.	1 to 2 in., two or more layers.

CHAPTER V—DETAILS OF DESIGN AND CONSTRUCTION

501—General

(*a*) The monolithic character of reinforced concrete construction creates problems in details of design as well as in construction that require adequate treatment if the structure is to be durable, structurally sound, and acceptable in appearance.

(*b*) To insure durability where the structure is exposed to the weather, the reinforcement should be protected by an adequate covering of concrete. For exposure to sea water, corrosive fluids, or high temperatures, extra precautions are necessary. In order to maintain a proper amount of covering the metal reinforcement should be accurately and firmly held in position.

(*c*) Only comparatively small structures can be cast without interruption. Consequently, construction joints in the concrete and splices in the metal reinforcement are required.

(*d*) In addition to construction joints it is frequently necessary to articulate a structure to provide for length changes due to temperature variation and shrinkage. Also in some cases joints are introduced for structural or design purposes, as in open spandrel or hinged arches and some types of framed structures. Joints of this character need special attention on the part of the designer and the construction organization if they are to function properly. Where concrete structures are exposed to water pressure, there is added to these requirements the necessity of maintaining watertightness.

(*e*) The use of reinforcement in distributing and minimizing the formation of cracks should be given careful attention.

(*f*) The following recommendations cover some of the more important construction details, and are intended to guide in the design as well as in the construction. These should be considered in connection with Sect. 501-S to 511-S of the specifications.

Details of Reinforcement

502—Splicing of Reinforcement

When it is necessary to splice reinforcement, the splice should develop the strength of the bar by bond resistance over the surface limited by the length of splice. In lapped splices the bars should be placed in contact and wired together. The minimum distance recommended in Sect. 504 should be considered to apply to the space remaining between a pair of bars so spliced and adjacent bars or splices. Wherever possible, splices of adjacent bars should be staggered. A welded or mechanical connection should develop the full strength of the bars.

503—Offsets in Column Reinforcement

When changes in the cross section of a compression member occur, the longitudinal reinforcement should be sloped the full length of the member or offset in a region where lateral support is provided sufficient to resist the transverse component of the thrust in the inclined portion of the offset. Where offsets are used, the slope of the inclined portion of the bars should be not more than 1 to 6 with respect to the axis of the members (see Sect. 854(*c*)).

504—Clearance and Embedment

Reinforcement bars should be located a sufficient distance from the surfaces of members and from each other to afford adequate embedment for bond resistance and for satisfactory placing. The minimum spacing between parallel bars should be 2½ times the diameter of round or 3 times the side dimension of square bars, but in no case should the clear distance between bars be less than 1½ times the maximum size of the coarse aggregate nor less than 1 in. in beams and girders, nor 1½ in. in columns. See Sect. 854 for recommendations concerning column reinforcement.

505—Fire Protection

(*a*) Metal reinforcement should be protected against fire by the minimum thicknesses of concrete shown in the following table for the various classes of structural members and types of aggregates (designated as Group 1 and Group 2, and defined in Specifications Sect. 225-S).

Fire Resistance	Minimum Thickness of Concrete (in.)			
	4 hr	3 hr	2 hr	1 hr
For columns, beams, girders, and unprotected ribbed slabs				
Group 1, Aggregate	1½	1½	1½	1
Group 2, Aggregate	2	1½	1½	1
For solid slabs				
Group 1, Aggregate	¾	¾	¾	¾
Group 2, Aggregate	1	¾	¾	¾

(*b*) In ribbed floor construction where ribs are spaced not more than 30 in. in the clear, and formed between permanent masonry filler blocks, or between permanent or removable forms, and having the additional protection of ¾ in. of portland cement or gypsum plaster applied directly to the ribs and masonry fillers, or to metal lath attached to or suspended below the ribbed construction, the fire protection requirements for the ribs should be those indicated in the table for solid slabs.

506—Moisture Protection

(*a*) At those surfaces of footings and other principal structural members in which the concrete is deposited directly against the ground, metal reinforcement should have a minimum covering of 3 in. of concrete. At other

surfaces of concrete exposed to the ground or to severe weathering conditions, metal reinforcement should be protected by not less than 2 in. of concrete. At undersides of slabs exposed to weather 1 in. should be provided.

(*b*) Where metal fabric in the form of wire mesh or expanded metal is used as reinforcement for protective coatings on columns, beams, or girders, it should have a minimum covering of 1½ in. for structures exposed to water, ground, or weather, and a minimum of ¾ in. for structures not so exposed.

(*c*) Where pneumatically applied mortar is used for moisture protection, it should not be less than 1½ in. in thickness and reinforced with metal fabric as provided in Sect. 406(*m*). The mesh should be securely fastened to the surface to be protected.

(*d*) In large and monumental structures such as large bridges, locks, and dams, it is recommended that the minimums enumerated above be increased.

(*e*) Structures or structural elements exposed to the injurious action of corrosive liquids and vapors require special designs of protective coverings.

507—Concrete in Sea Water

(*a*) For the protection of the reinforcement where concrete is exposed to sea water both the quality of the concrete and the thickness of the protection should fulfill more than ordinary requirements. The minimum water contents shown in Table 1, Section 303, are recommended. The placing should be in accordance with the specification paragraphs, 420-S and 421-S.

(*b*) The depth of protection for all metal reinforcement, including supports, ties, and stirrups, should be a minimum of 3 in. at all plane or curved surfaces and 4 in. near the corners of exposed members.

508—Future Bonding

Where reinforcing bars are to be left protruding from a structure for the purpose of bonding with future additions, special care should be taken to protect them against injury or corrosion.

Expansion and Contraction Joints

509—Purpose and Location

(*a*) If a reinforced concrete structure is free to expand and contract with variations in temperature or moisture conditions (uniform over the section), no stresses of any importance will be developed. When the movement of the structure is restrained, however, or when temperature or moisture variations are not uniform over the section, stresses are introduced which should be provided for in the design.

(*b*) Points requiring special consideration are located where large changes in cross section occur or at corners in long members where expansions or contractions may result in rupture of the side members. No amount of reinforcement will prevent the formation of cracks in a restrained structure

in which the required change in length exceeds the extensibility of the concrete, but reinforcement properly designed will serve to distribute the cracks.

(*c*) Joints providing a complete separation in the structure, when properly located, can relieve the restraint and prevent or greatly minimize the development of cracks. Such joints should be carefully designed with respect to the type of structure and should provide for the full expected movements without introducing local stresses severe enough to rupture the concrete. They should be located at predetermined points and fully detailed on the drawings. They may or may not be designed to carry load or distribute stress across the joint. Frequently this type of joint requires some form of protection to keep out extraneous material.

510—Expansion Joints in Long Buildings

(*a*) Expansion joints are expensive and in some cases difficult to maintain. They are, therefore, to be avoided if possible. In relatively short buildings, expansion and contraction can be provided for by additional reinforcement. No arbitrary spacing for joints in long buildings can be generally applicable. In heated buildings joints can be spaced farther apart than in unheated buildings. Also, where the outside walls are of brick or of stone ashlar backed with brick, or where otherwise insulated, the joints can be farther apart than with exterior walls of lower insulating value.

(*b*) In localities with large temperature ranges, the spacing of joints for the most severe conditions of exposure (uninsulated walls and unheated buildings) should not exceed 200 ft. Under favorable conditions buildings 400 to 500 ft long have been built without joints even in localities with large temperature ranges.

(*c*) In localities with small temperature ranges, the spacing of joints for unheated buildings or with uninsulated walls should not exceed 300 ft. In such localities buildings up to 700 ft long have been successfully built without joints where other conditions were favorable.

(*d*) In roof construction, provision for expansion is an important factor. The joints in the roof may be required at more frequent intervals than in the other portions of the building because of more severe exposure. In some cases expansion joints spaced 100 ft apart have been provided in roofs and not in walls or floors.

(*e*) Joints should be located at junctions in L-, T-, or U-shaped buildings and at points where the building is weakened by large openings in the floor construction, such as at light wells, stairs, or elevators. Joints should provide for a complete separation from the top of the footings to the roof, preferably by separate columns and girders.

511—Retaining Walls

For retaining walls and similar structures subject to large temperature and moisture changes, the details suggested in Sect. 877 are recommended.

512—Concrete Trestles

For concrete trestles and similar structures the spacing of joints will depend upon the temperature range, flexibility of the supports, and other structural requirements. In general, for structures of this type it is desirable to place the joints not farther apart than 125 ft. For this type of construction joints, where heavy loads are being transmitted, sliding joints should not be used.

Construction Joints

513—Location of Joints

Wherever it is necessary to interrupt the placing of the concrete, an effort should be made to form a joint that will least impair the appearance or serviceability of the member or structure. Where such joints are objectionable, the drawings should clearly indicate the limits of the various sections to be placed at one operation and the joints desired should be fully detailed. When construction joints cannot be avoided the method of procedure given in Sect. 508-S to 511-S of the specifications should be followed.

514—Watertight Joints

Where construction joints are necessary in structures exposed to water pressure, or where for other reasons the joints must be watertight, noncorrosive metal water stops should be installed.

CHAPTER VI—WATERPROOFING AND PROTECTIVE TREATMENTS

601—General

The questions of when to waterproof and what method to use are so largely matters of individual cases that it is not possible to offer specific recommendations that will be generally applicable. In the following paragraphs some comment is offered on the general aspects of the problem. It is realized that experienced engineers are likely to be well informed on these subjects, but this brief statement of the factors involved is intended to serve as a background for the satisfactory solution in any individual case.

602—Watertightness of Concrete

(*a*) Many studies of permeability have shown that concrete of proportions suitable for structural or hydraulic work, if properly placed and adequately cured, is watertight for all practical purposes even under very high pressures. Failure to obtain watertight structures therefore is due either to improper concrete practice or to such structural features as cracks, joints, etc., which permit the passage of water.

(*b*) Observations on structures in service have shown that where water finds its way through the concrete itself, it is almost invariably through defective spots resulting from improper placement or mix proportions. By far the most common source of leakage observed is at the planes of contact between successive lifts. This usually results from improper bond or from porous concrete at the top of the lift due to watergain. Another common source of leakage is found in defective areas resulting from honeycomb or segregation during placing. Obviously, the prevention of such defects is a first requirement of watertight construction.

603—Presence of Cracks and Joints

(*a*) No matter how impervious the concrete may be, or how perfectly placed, there is always the possibility of leakage through expansion joints, construction joints, or cracks. In Sect. 514, the use of non-corrosive water stops at joints is recommended where watertightness is required.

(*b*) Cracks, such as might result from load, settlement, temperature changes, or shrinkage of the concrete may be the source of considerable and annoying leakage in a structure exposed to direct water pressure. Provision against the formation of such cracks can be made by careful attention to all features of design. Spacing and arrangement of contraction joints and proper distribution of reinforcement can accomplish much in the prevention of cracks which will permit the entrance of water.

604—Importance of Drainage

Too much emphasis cannot be placed on the need for drainage around the structure where unsightliness or damage will result from the penetration

of water. In many cases, proper drainage would be all that is needed to preserve the structure or to protect the interior. In the opinion of this committee, drainage should be considered not as an adjunct to waterproofing, but rather as a first requirement to which waterproofing is added as a further protection.

605—Need for Some Type of Protection

In many types of structures exposed on one side to direct water pressure, it is important that the other side be absolutely dry. In the case of such structures, some method of waterproofing may be necessary which takes into account the possibility of the occurrence of structural cracks or the presence of defective spots in the concrete. Some of the methods mentioned below for waterproofing the concrete without a membrane may be effective in such cases, or an outside waterproof membrane may be needed. Where a membrane is necessary, the materials to be used and the methods of applying them should be those best adapted to the particular location or structure. The problems of this type of waterproofing are not peculiar to concrete construction and are therefore outside the scope of these recommendations.

606—Protection Against Weathering

(*a*) Although concrete of normal proportions, properly placed and cured, is impervious to the actual passage of water under pressure, it is not immune to the passage of water due to capillary forces. As indicated in Table 1 of Sect. 303(*b*), concrete even though properly made and cured, is affected by weathering in proportion to the severity of exposure and to the water-cement ratio of the paste. The greater the water-cement ratio, the greater the amount of free water that may be present and the more destructive the effect of the repeated freezing and thawing and wetting and drying. Laboratory tests, as well as field experience, have shown that a high degree of resistance can be obtained with properly placed and well-cured concrete by the use of low water-cement ratios. Low water-cement ratios require the use of rich mixes or some method of placing which permits concrete of stiffer consistencies to be properly consolidated.

(*b*) There is also evidence from both experiment and experience to show that certain protective coatings which are effective in sealing the concrete to the penetration of moisture are effective in increasing the resistance to the destructive action of alternate freezing and thawing. Such protective coatings or a membrane waterproofing, therefore, may frequently be necessary as a protection against weathering.

607—Dampproofing

(*a*) Water which enters the concrete wall by absorption will be distributed by the capillary forces throughout the concrete until a condition of saturation is reached or until evaporation balances the inflow. If there is a continuing supply of free water available on one surface and evaporation can take place from another, there will be a continuing passage of water. If the air becomes saturated or the temperature drops sufficiently, moisture

will condense on the wall. When this occurs, or if a seal coat is applied to the face away from the source of the moisture, the outflow of water ceases and saturation of the concrete is encouraged. The prevention of moisture penetration by capillarity is commonly referred to as "dampproofing" as contrasted with "waterproofing," which implies the prevention of an actual flow of water through the structure.

(*b*) The appearance of moisture on a wall does not always indicate, of course, that the water vapor in the air is entirely due to passage of water through the wall. Oftentimes, dampness on the inside of a wall is mistakenly ascribed to moisture penetration, when in fact it is merely the result of condensation, on the cold wall, of moisture which originated elsewhere.

(*c*) Dampness due to absorbed water or condensed water vapor can develop on and within concretes through which water will not "flow" even under great pressure. The remedy is to seal the pores on the side exposed to the moisture. Most of the methods mentioned below for waterproofing should be effective in preventing the entry of water into concrete. Other and more simple methods might also be effective. The use of a seal coat on the side away from the water may be effective for some time, but if the wall is subject to freezing temperatures the use of such seal coat may in the long run result in greater damage than leaving the wall unprotected.

608—Protection of Reinforcement

Spalling of concrete due to corrosion of the reinforcement is frequently the cause of damage to structures. In structures exposed alternately to wetting and drying, this is probably the most common cause of deterioration. Where the concrete protection is in accordance with Sect. 506, the only special requirement for protection of the reinforcement will be that necessary to prevent the moisture reaching the reinforcement through cracks or defective areas.

609—Protection Against Corrosive Substances

Research and experience have developed various types of treatments for protecting concrete against the effect of exposure to various types of substances. The committee has assembled in Appendix 1 the best available information on the effect of some of the more common types of substances and the treatments which have been found helpful in retarding or preventing corrosion.

610—Coatings on the Side Away from the Water Pressure

The desirable procedure in waterproofing a structure is to apply protection on the side exposed to water pressure. Frequently, however, this is impossible and it is necessary to apply waterproofing on the opposite side. Where the waterproofed surface is protected from freezing temperatures, this procedure has some advantage in that in the case of failure of the waterproofing it is easier to locate the source of weakness and make the necessary repair. Where the waterproofed surface is to be exposed to freezing temperatures, however, the method is not to be recommended. The

freezing of water in the concrete immediately underneath the protective coating will not only damage the coating, but injure the concrete itself. The concrete may be affected more rapidly with the coating than it would if the coating were absent, when there would be less opportunity for the concrete to become saturated at the surface.

611—Waterproofing with Portland Cement Mortar

(*a*) A plaster coat of portland cement mortar on the side of a wall exposed to water pressure, when properly applied and cured, will effectively protect porous concrete against the penetration of water under pressure. However, any structural movement resulting from load, settlement, shrinkage, etc., which will crack the structure, will crack the plaster, thereby destroying its waterproofing value at these points. The use of this type of waterproofing, of course, would require that any cracks existing in the concrete be chipped out and filled with mortar before applying the plaster coat.

(*b*) Portland cement plaster applied on the side of the structure away from the water pressure has been successfully used against considerable heads. Cracks and defective spots are readily filled by mortar applied from the inside. When skillfully done, this method can be used to shut off actual flowing leaks. When the quantity of water flow is considerable, some accelerating agent, which will reduce the setting time to a few minutes, may be necessary.

(*c*) This method of waterproofing has the advantage that cracks occurring after the plaster is in place can be readily located and repaired. It does not, of course, prevent possible damage to the structure from corrosion or weathering even though the interior may be kept dry. It should not be used where the surface is to be exposed to freezing temperatures. The method, however, has its uses and in some instances may be the only possible one.

(*d*) Good plastering technique is required for successful waterproofing with portland cement plaster, whether applied on the inside or the outside. This includes such details as clean surfaces, proper suction at the time of application, plastic consistency, and the proper curing of each coat. The mortar should be about a 1 : 2 mix applied in at least two coats, each coat about ⅜ in. thick. Powdered iron preparations (Sect. 613(*e*)) are sometimes added to the mortar.

612—Integral Waterproofing

(*a*) *Powdered Admixtures.*—Misconception of the function of admixtures and frequent overstatement of their properties have led to much misunderstanding regarding their use. In very lean mixtures almost any fine, inert material will improve the watertightness of concrete. This improvement comes about in two ways. First, with the extra fines the paste will have a more plastic consistency which will segregate less and be more watertight. Second, the more plastic paste will improve the workability of the concrete and thereby guard against those defects in placing which leave open channels for water to pass through the member.

In rich mixes, on the other hand, where the cement-water paste is already of plastic consistency, and of sufficient quantity to give the needed workability, powdered admixtures serve no useful purpose so far as watertightness is concerned. For mixtures in this range most of the powdered admixtures require increased water content, as compared with the plain mix, which reduces the quality of the paste and detracts from its watertightness.

The field of powdered admixtures, therefore, for waterproofing concrete will depend upon the character of the concrete mix just as much as upon the characteristics of the admixtures. Lean mixtures or normal mixtures deficient in fines in the aggregate can be improved by some of the admixtures. On the other hand, rich mixes, and normal mixes in which adequate fines are present, may be reduced in watertightness by the presence of these added fines.

(*b*) *Water-Repellent Admixtures.*—Stearates or other water-repellent materials have found considerable use as admixtures for concrete where the penetration of moisture is to be retarded. These materials reduce the absorption and retard penetration of moisture by capillary action. They do not seem to be effective as waterproofing when the concrete is exposed to direct water pressure. Some of these water-repellent admixtures improve the workability of concrete and thereby may improve the watertightness of a wall exposed to direct water pressure.

613—Waterproofing with Surface Treatments

(*a*) There are a number of surface materials which can be applied to concrete for protection of the surface against weathering or other attack. Those referred to in Sect. 609 and listed in detail in Appendix 1 are materials which have been found especially effective for certain uses. Some of these may be sufficiently permanent to serve as a waterproofing or dampproofing coating. In the following paragraphs are listed some of those which have been found particularly adaptable.

As in the case of cement mortar plaster, any structural movement which produces a crack will break these applied coatings and destroy their waterproofing value at these points. Likewise, none of these surface treatments is of sufficient body or strength to span cracks already in the structure and prevent the entrance of water. As pointed out in Sect. 610, these materials, when used on the side away from the pressure, may accelerate deterioration of a wall if exposed to freezing temperature.

(*b*) *Bituminous Coatings.*—There are a number of asphaltic and tar coatings which are available for application to concrete. Some of these are to be applied hot; others, which depend for their hardening on the evaporation of a liquifier, are to be applied cold. The extent to which these materials can waterproof concrete and the period over which the protection will remain effective, depend not only upon the materials themselves, but on the condition of the concrete to which they are applied and the type of exposure to which the surfaces will be subjected. This same comment might with equal propriety be applied to the other materials mentioned below.

(*c*) *Oil, Oil Paints, or Oil Resin Combinations.*—Linseed oil by itself, or in combination with resinous varnishes, makes a very satisfactory coating material for ordinary weathering and many other types of exposure. Oil paints based on linseed or other weather-resisting oil also have value. The preparation of the surface and the application of the materials should be done in accordance with the best painting technique with particular reference to the type of materials being used.

(*d*) *Portland Cement Paints.*—Mixtures of portland cement and water or specially prepared combinations consisting mainly of portland cement are shown to have considerable value in resisting the penetration of water into concrete surfaces under conditions of moderate exposure. The use of these materials requires that special attention be given to curing methods to develop their greatest effectiveness.

(*e*) *Powdered Iron Preparations.*—Mixtures of pulverized iron and cement, usually with some agent designed to hasten the oxidation of the iron, have been used for waterproofing concrete surfaces. These are usually applied with a brush, either in a thin coating like a paint, or in a stiffer consistency to a measurable thickness. The waterproofing effect is considered to result from the formation of the oxide of iron within the pores of the concrete. The agent most commonly used to accelerate the oxidation of the iron is ammonium chloride. These materials are also sometimes mixed with cement mortar for use in waterproofing (see Sect. 611).

(*f*) *Proprietary Surface Treatments.*—Many surface treatments of a proprietary nature are available for painting concrete which are based on some of the foregoing or similar materials. The use of such proprietary compounds should be restricted to those which have been proven by service test and which are susceptible to tests that will insure uniformity. They should always be limited to the type of service for which they are intended and the method of application should be strictly in accordance with the directions of the manufacturer.

614—Bituminous Membrane Waterproofing

(*a*) This method is particularly adaptable to large areas where there is some uncertainty as to the possibility of further cracking in the structure which would render other forms of waterproofing ineffective. It involves the use of a membrane consisting of one or more layers of bitumen-saturated cotton fabric or felt, or combinations of both materials cemented together (and to the surface waterproofed if a priming coat is used) by means of bituminous coatings. The bitumen to be used for the saturant and coating should be either asphalt or tar. The technique of applying this type of waterproofing is well established and organizations and workmen experienced in its use are generally available.

(*b*) Where there is any possibility that the membrane will be punctured by the backfilling material, it should be protected by an additional layer of masonry or by some such method as portland cement mortar or bituminous mastic, or by an asphalt blanket or bituminous mastic blocks.

CHAPTER VII—SURFACE FINISHES

701—General

(*a*) Surface finish is a term used to denote the process or method of mixing, placing, and treating concrete to produce a desired appearance and texture of the surface.

(*b*) The requirements of the sections of this Report relating to materials, forms, mixing, curing, conveying, depositing, and protection of concrete should apply except as they may be modified by these special requirements.

(*c*) Concrete should be placed in one continuous operation between prescribed expansion or construction joints, unless the drawings indicate other points where the placing of concrete can be discontinued.

(*d*) The same brand of cement, the same kind and size of aggregates, the same proportions and type of finish should be used where it is desired to duplicate texture and appearance on any showing surface.

702—Forms

(*a*) Forms for finished surfaces should be smooth and mortar-tight. If wood forms are used, the boards must be uniform in thickness, tongued and grooved, smoothly finished on the surface next to the concrete, evenly matched and tightly placed, except where the desired surface or appearance requires special treatment.

(*b*) The forms should be so constructed as to be removable in sections without marring or damaging the surface of the concrete. Forms should be removed as soon as possible in order to make necessary repairs and finish the surface. As soon as forms are removed any undesired fins or other projections on the surface should be carefully removed, offsets leveled, and voids or damaged places immediately saturated with water and repaired by filling with a concrete or mortar of the same composition as was used in the surface. After making the necessary repairs the surface should be finished with a wood float so as to be free from streaks, discolorations, or other imperfections. Plastering should not be permitted and a steel trowel should not be used to finish surfaces.

703—Preparation for Surface Finish

(*a*) Where a surface mortar is to be the basis of the finish, the coarse aggregate should be worked back from the forms with a suitable tool so as to bring a full surface of mortar against the forms, care being taken to prevent the formation of voids and aggregate pockets.

(*b*) Where a special surface finish is called for on the drawings or in the specifications, the work of preparation should be carried out as specified.

DECORATIVE FINISHES

704—General

(*a*) Modern materials and methods may be used in the decorative treatment of architectural concrete to express the designer's ideas and taste in a wide variety of motifs, color, and texture.

(*b*) Decorative finishes on exposed concrete surfaces may be classified as: (1) Precast ornament, (2) monolithic ornament, (3) surface treatment after removal of forms, and (4) applied finish.

705—Precast Ornament

Precast ornamental units should be applied to the inside face of forms or set in framed openings in the structural form work. Such units are ordinarily made of cast stone from approved models. Positive anchorage into concrete should be made by means of rabbets, lugs, non-corrodible metal anchors, or other approved means of anchorage.

706—Monolithic Ornament

(*a*) Ornament is produced monolithically by forming concrete with negative models or molds. The precast models or stamped forms should be accurately and securely set in the structural forms. Special treatment of absorptive molds should be provided to prevent the absorption of moisture. Particular care is required in the design of the mixtures and in placing ornamental concrete to assure structural soundness and the desired finish.

(*b*) Finished samples of positive models should be submitted and approved as to craftsmanship, form, texture, and appearance.

(*c*) Construction joints in monolithic ornament, when necessary, should be located and constructed in such a manner as to be unobjectionable in the finished work. When molds are removed in less than 7 days, the surface should be immediately sprinkled with water and kept wet until the concrete is at least 7 days old. All ornamental work should be protected from damage until it is accepted.

707—Surface Treatment after Removal of Forms

(*a*) The desired appearance, texture, and finish for the surface should be determined from sample surfaces. Form linings, such as sheet metal, fiber, or manufactured board, may be used to produce concrete surfaces with specified markings or patterns.

(*b*) Where a special facing mix with selected aggregates is to be used, it should be placed to the required thickness and in such a manner as to bond securely with the backup concrete.

(*c*) The time of removal of face forms will depend upon the type of surface finish desired. For scrubbed finish the face forms should be removed as soon as safety permits and before the surface becomes too hard. For rubbed, sand-blasted, or tooled finishes, the surface must be thoroughly cured and hard before finishing.

708—Type of Finish

(*a*) *Rubbed Finish*.—The surface should be thoroughly wetted, and rubbed or ground with carborundum or other abrasive until it presents a uniform and smooth appearance. Cement mortar may be used in the rubbing, but the surface should not be brush coated with cement or grout after rubbing.

(*b*) *Scrubbed Finish*.—The surface should be thoroughly wetted and scrubbed with stiff fiber or wire brushes using water freely until the surface film of mortar is removed and the aggregate uniformly exposed. The surface should then be rinsed with clean water. If portions of the surface have become too hard to scrub in equal relief, dilute hydrochloric acid (commercial acid diluted with 4 to 10 parts water) may be used to facilitate the scrubbing, the acid being removed from the finished surface with clean water.

(*c*) *Sand-Blasted Finish*.—The thoroughly cured concrete surface should be sand-blasted with hard, sharp sand until the aggregate is in uniform relief.

(*d*) *Tooled Finish*.—The thoroughly cured concrete surface should be dressed with tools to a uniform texture and even face. The tools ordinarily used are electric or air or hand tools, giving various textured surfaces such as hand-tooled, rough or fine pointed, crandalled, or bush-hammered, as specified and as selected from sample surfaces.

(*e*) *Sand-Floated Finish*.—The forms should be removed before the surface has fully hardened; the surface wetted and rubbed with a wood float by a uniform circular motion, fine sand being rubbed into the surface until the resulting finish is even and uniform.

709—Applied Finish

(*a*) With applied stucco or plaster finishes the surface of the concrete should be removed to a depth of at least $\frac{1}{16}$ in., exposing the aggregate and leaving a clean, firm, granular surface for the permanent adhesion of the finish. A chemical compound may be used on the inside of forms to retard the setting of the surface concrete, in which case all loose material should be removed and surface thoroughly cleaned before finishing. If mechanical treatment, such as hacking or chipping or grinding, is used, care should be taken to leave no untreated surfaces. A mechanical bonding surface may be formed by using a suitable form material or form lining.

(*b*) When applying the first coat of stucco or plaster, the concrete should be thoroughly wetted but should have no free water on the surface.

Wearing Surfaces

710—One-Course Work

In one-course work the slabs should be placed continuously for the full thickness without change of proportions. The least quantity of mixing water should be used to meet placing conditions. The proportions should be such that not over 5 gal of mixing water, including that carried by the aggregate, is used per 94-lb sack of cement.

711—Two-Course Work

(*a*) In two-course work the wearing surface or topping may be applied either before or after the base has hardened. For pavements and driveways the top coat should have a minimum thickness of 2 in. Floors subject to heavy wear should have a minimum thickness of 1 in. For walks and ordinary floors ¾ in. may be used.

(*b*) On an unhardened base the concrete topping should be applied within 45 min after the concrete base is in place. The unhardened base course should be free from water, laitance, foreign matter, and loose particles.

(*c*) For a hardened base the surface should be roughened to improve bonding, should be thoroughly wetted just prior to placing the finish, and a thin coat of neat cement paste should be broomed into the surface for a short distance ahead of the topping. The wearing course should be immediately applied.

712—Aggregates

Aggregates should meet the requirements of specification Sect. 207-S to 219-S. Coarse aggregates should be graded from No. 4 to ⅜ in. or from No. 4 to ½ in.

713—Proportions

For surfaces not subjected to severe wear or heavy abrasion the proportion should be 1 part cement to not more than 2 parts fine aggregate by volume. For surfaces subjected to severe wear or heavy abrasion the proportions should be 1 part cement, not more than 1 part fine aggregate, and not more than 2 parts coarse aggregate of the specified grading.

714—Finishing

(*a*) Topping applied to an unhardened base should be struck off to a true and even surface and finished to the desired smoothness with a wood float and steel trowel, or with a mechanical float machine and steel trowel. Cement or a mixture of cement and aggregate should not be sprinkled on the surface to absorb moisture or to stiffen the mix.

(*b*) Topping applied to a hardened base should be struck off and compacted by rolling or with tampers or vibrators. The surface should be finished to the desired smoothness with a wood float and steel trowel, or with a mechanical float machine and steel trowel.

715—Curing

As soon as the finished wearing course has hardened sufficiently to prevent marring it should be sprinkled with water or covered with sand or other approved coverings and kept continuously wet for at least 10 days where normal portland cement is used, or 3 days where high early strength portland cement is used.

TERRAZZO

716—Methods of Bonding

Terrazzo finish should be bonded to the structural concrete base following Method 1, or separated from the concrete base or supporting surface following Method 2.

Terrazzo Method 1

717—Treatment of Base

The surface of the structural concrete base or fill course upon which terrazzo is to be placed should be at least 2 in. below the finished floor level. The base course should be cleaned of all loose and foreign materials, thoroughly wetted, and a thin coat of neat cement broomed into the surface for a short distance ahead of the placing of the mortar base.

718—Mortar Base Course

Upon the concrete base should be placed a mortar base course at least $1\frac{1}{4}$ in. thick, with the surface struck off at least $\frac{3}{4}$ in. below the finished floor level. The mortar base should be composed of 1 part portland cement to not more than 4 parts sand and sufficient water to produce a mortar of the stiffest consistency that can be struck off cleanly with a straight edge.

719—Metal Strips

Metal dividing strips of the type and width desired and at least 20 gage in thickness should be inserted in the mortar base before it hardens and should be so positioned as to control the location of cracks and conform to the design or pattern required. The tops of the metal dividing strips should extend at least $\frac{1}{32}$ in. above the finished level of the floor.

720—Terrazzo Mix

The terrazzo mixture should consist of 1 part gray, white, or colored portland cement, as desired, to not more than 2 parts by weight of marble chips, stone chips, or abrasive aggregate, or a mixture of these of the required grading, quality, and color. The consistency of the terrazzo mixture should be plastic and workable; wet or fluid mixes should be avoided. Coloring agents other than aggregates should be mineral pigments.

721—Placing

When the mortar base has hardened sufficiently to withstand rolling, the terrazzo mixture should be placed to the level of the tops of the metal dividing strips. After being struck off the surface should be rolled lengthwise and crosswise to secure a thorough compacting. Additional aggregates of the quality, grading, and color required should be spread over the surface during the rolling until at least 70% of the finished surface is composed of aggregate. Immediately after rolling the surface should be floated and troweled once without attempting to remove trowel marks.

722—Grinding and Finishing

After the terrazzo concrete has hardened sufficiently to prevent dislodgment of the aggregate it should be ground down by hand or with an approved type of grinding machine shod with rapid cutting carborundum stone or other abrasive. The floor should be kept wet during the grinding process. All material ground off should be removed by squeegee and by flushing with water. Air holes and other blemishes and imperfections should be filled with a thin grout composed of neat portland cement paste spread over and worked into the surface. After the cement paste has hardened for at least 72 hr the floor surface should receive a second or final grinding sufficient to remove the film of cement paste.

723—Curing

See Sect. 715.

724—Cleaning

After removing all loose material the finished floor should be scrubbed clean with warm water and soft soap and mopped dry.

Terrazzo Method 2

725—Sand and Paper Course

The surface of the structural base or fill course upon which the terrazzo is to be placed should be $2\frac{1}{4}$ in. below the finished level of the floor. Over this surface should be placed a layer of fine, dry sand about $\frac{1}{4}$ in. in thickness. The sand should be struck off with a straight edge to a smooth surface not less than 2 in. below the finished floor level. The surface of the sand should be covered with waterproofed paper. The paper should be so placed that all side and end laps are at least 1 in. wide.

726—Construction

The mortar base course should be placed upon the paper and terrazzo finish laid as described for Method 1 (Sect. 717 to 724).

Use of Color

727—Pigments

(*a*) *Quality of Colors.*—Only those pigments should be used which are insoluble in water and free from acids and soluble salts, and which are definitely known not to react with the calcium hydroxide set free during the hardening of the concrete, and which are further known through service not to be fugitive. Inorganic pigments are to be preferred; organic coloring agents should be used only when known to have the above characteristics.

(*b*) *Limiting Amounts.*—Pigments having a specific gravity of 3.0 or higher should be used in amounts not greater than 10% of the weight of the cement. The lighter weight pigments should be used in lesser amounts. When in doubt as to the permissible amount that should be used for any particular job, tests should be made using all the materials

and in the proportions indicated for the job, and noting the appearance and effect on the physical properties, particularly strength and volume change of the concrete.

(*c*) *Mixing.*—Preferably, the pigment should be ground with the cement; otherwise, it should be thoroughly mixed dry with the cement and fine aggregate until a uniform color is secured throughout.

728—Colored Aggregates

Colored aggregates may be used when tests have shown that they will produce a concrete having the desired properties and that the colors are not fugitive and will not react with the calcium hydroxide set free during the hardening of the cement. Naturally occurring aggregates, and those produced from crushing and sizing vitrified ceramic products, and colored glasses have generally proved satisfactory. These aggregates should be used as normal aggregates.

PAINTS

729—Classification

(*a*) Paints commonly used for concrete may be of three classes: Lead and oil paints, cement and oil paints, and portland cement paints.

(*b*) "Lead and Oil Paints" is the general term used for paints based upon the principle of grinding a pigment, such as white lead, in a vehicle such as linseed oil with the addition of driers and thinners. Modern paints of this type may be composed of many other pigments besides white lead, and other vehicles besides linseed oil.

(*c*) "Cement and Oil Paints" is the general term used for paints made by grinding portland cement and pigment in an oil or synthetic resin vehicle.

(*d*) "Portland Cement Paints" is the general term for mixtures of portland cement and pigment prepared for application by mixing with water.

730—Application of Lead and Oil Paints, Cement and Oil Paints

(*a*) *Seasoning of Concrete.*—A period of 8 to 10 weeks following the curing period should be allowed for concrete to season before painting. The alkalinity of the surface should then be reduced by applying a solution consisting of 2 to 3 lb of zinc sulfate per gal of water. When thoroughly dry, all crystals should be brushed from the surface. This treatment is not necessary on old concrete or stucco.

(*b*) *Condition of Surface.*—The surface should be clean and free from dirt, oil, grease, and efflorescence, and should be thoroughly dry at the time of painting. If water dashed on the surface from a brush is rapidly absorbed, the surface may be assumed to be dry enough for painting.

(*c*) *Number of Coats.*—The number of coats necessary will depend on the porosity of the surface and in general should be not less than three on surfaces previously unpainted. The first coat should be well thinned for penetration. The second coat should contain more pigment, the amount depending on the suction remaining. The number of undercoats should

be sufficient so that oil will not be drawn from the finish coat and it will dry to a uniform gloss and color.

731—Application of Portland Cement Paints

(*a*) *Condition of Surface.*—The surface should be clean and free from dirt, oil, grease, and efflorescence, and should be uniformly damp at the time of painting. The surface should be dampened sufficiently in advance so that free water has drained from the surface.

(*b*) *Application and Curing.*—After the first coat of paint has hardened sufficiently to prevent damage to the surface, it should be moistened with water applied with a fine spray and a second coat of paint applied. As soon as it is possible to do so without marring the surface, the second coat of paint should be sprayed with water and the surface kept wet for at least 3 days to insure proper curing and hardening of the paint.

CHAPTER VIII—DESIGN

801—General

(*a*) In presenting recommendations for the design of reinforced concrete structures the committee has given consideration to such recent developments as plastic flow, or time yield, in concrete, and the application of the elastic frame theory in design. Concerning plastic flow, the committee adopts the prevailing opinion that in flexural members there is an adjustment in the concrete and steel stresses of moderate amounts, but that the load carrying capacity of the member is not materially affected. In fact, according to this opinion plastic flow may aid the structure in producing a more uniform stress distribution by yielding at heavily stressed sections.

(*b*) In regard to the elastic frame theory the committee takes the position that the design of a monolithic frame as an aggregation of isolated members is not tenable. Frames of buildings and other types of structures are generally built with the various members rigidly connected with one another. This feature of continuity of construction complicates the problem of determining the character and amount of bending at critical sections of the frame.

(*c*) In the design of buildings it has been for many years common practice to design columns and beams as isolated members, the columns as compression members axially loaded, and the floor system by prescribed coefficients for moments at the ends and in the center of the span. In some cases prescribed moment coefficients have also been used to evaluate the bending in columns induced by unbalanced loadings from the floor system.

(*d*) Although such practice has apparently resulted in safe design in the case of buildings with uniform column spacings, it has become increasingly clear with the advent of newer methods of analysis that the degree of safety was neither uniform throughout the structure nor in some cases equal to that intended in the design. In the rather frequent cases of unequal spacing of columns or story heights, the design based on the usual moment coefficients often leads to improper design, and quite generally to wide departure from uniformity of factor of safety in the various members of the structure.

(*e*) The committee recognizes that more exact methods of analysis are now available for general use in the design of buildings and other framed structures, also that they may be simplified without undue sacrifice of accuracy. These methods will result in better provision for the effects due to continuity and should thereby secure a more uniform degree of safety. The need for such improvement in design becomes more important with the introduction of higher strengths and lighter weights of concrete and the accompanying higher working stresses. The consideration of continuity is especially important in cases of unequal spans alternately loaded where the ratio of live to dead load is large.

802—Assumptions

The design of reinforced concrete frames, beams, and slabs, is based on the following assumptions:

1. Plane sections normal to the axis remain plane after bending.
2. Tensile strength of concrete is negligible in resisting bending.
3. The ratio of the modulus of elasticity of steel to that of concrete, for concrete of a given strength, is constant in flexural members within the range of working stresses. The ratio, however, is not considered as fixed in the case of columns or in the case of compression reinforcement in flexure where, due to plastic flow, the reinforcement will be more highly stressed than indicated by a constant value of the modular ratio.
4. The moment of inertia of flexural members, for purposes of computing the relative stiffness, may be that of the gross cross-sectional area of the member, making reasonable allowance for the effect of flange width in T-beams permitted in 804(*d*). For columns or other compression members the transformed area of the steel reinforcement should be included.
5. Temperature changes and shrinkage are neglected in the computation of stresses for buildings of ordinary size. (See Sect. 510 for recommendations regarding expansion joints and temperature reinforcement.)
6. In engineering structures such as arches, elastic frame bridges, and similar types where temperature change is an important factor in the resultant stresses, it is assumed that the temperature change is uniformly distributed throughout the member affected. For design purposes the coefficient for temperature change may be taken as 0.000006 per degree F.
7. Where shrinkage is considered a factor in design it may be assumed to range from 0.00015 to 0.00045, depending upon the size of the member and the moisture conditions.

803—Superimposed Loads

(*a*) *Uniform Loads.*—It is generally recognized that the conventional assumption of uniform load is a device employed for convenience of design and is only an approximation to floor loadings found in service. Uniform load, however, has been found to cover adequately the usual varieties of partial loadings in buildings and may be accepted unless the loads are permanently fixed in position. For the usual building, the following arrangement of loaded spans for computing maximum positive and negative bending moments, respectively, is recommended, unless conditions indicate a need for more careful analysis:

1. Alternate spans loaded, with a maximum of three loaded spans.
2. Two adjacent spans loaded, other spans unloaded.

(*b*) *Moving Loads.*—In structures subject to moving loads the bending moments and shears to be used in design should be the maximum values

which may result from any probable position of the conventional or actual system of loads to be provided for.

(c) *Impact.*—For moving or other impact-producing loads suitable allowance should be made in the various portions of the structure for these effects. Such allowance should take into account the ratio of the live to dead load.

(d) *Structures in Earthquake Regions.*—In structures subject to earthquake shocks special analysis should be made to determine the probable stresses which should be added to those resulting from static or moving loads.

Design of Frames, Beams, and One-Way Slabs

804—General

(a) *Effective Span for Determining Bending Moments.*—

1. In continuous beams and slabs or elastic frames the effective span should be taken as the center-to-center distance between supports.

2. In beams or slabs of one span freely supported, the effective span length should be taken as the center-to-center distance between supports, but need not exceed the clear span plus the distances to centers of the required bearing areas.

3. In slabs built integrally with supports capable of fully restraining the slab the effective span length may be taken as the clear distance between supports.

(b) *Lateral Support.*—If the distance between lateral supports of beams exceeds 24 times the least width of the compression face, the allowable unit stress should be reduced. In no case should the distance between supports be more than 36 times the least width, at which limit the reduction in stress should be 50%. Proportionate reduction for intermediate ratios of span to width should be made.

(c) *Compression Reinforcement in Beams.*—Compression reinforcement in girders or beams should be secured against buckling by ties or stirrups adequately anchored in the concrete and spaced not more than 16 bar diameters apart. Where compression reinforcement is used its effectiveness in resisting bending may be taken at twice the value indicated from the calculations, assuming a straight-line relation between stress and strain and the modular ratio given in Table 7, Sect. 878. However, in no case should a stress in compressive reinforcement greater than 16,000 lb per sq in. be allowed.

(d) T- *and* L-*Beams, Limitations.*—

1. In T- *and* L-beam construction the slab and beam should be built integrally or otherwise effectively bound together.

2. The effective flange width used in the design of T-beams should not exceed one-fourth of the span length of the beam, nor should the overhanging width on either side of the web exceed eight times the thickness of the slab or one-half the clear distance to the next beam.

3. For beams having a flange on one side only, the effective overhanging flange width should not exceed one-twelfth of the span length of the beam, nor six times the thickness of the slab, nor one-half the clear distance to the next beam.

(*e*) *Transverse Reinforcement in Flange of* T- *and* L-*Beams.*—Where the principal slab reinforcement is parallel to the beam, transverse reinforcement should be provided in the top of the slab. This reinforcement may be designed to carry the load on that portion of the slab which is assumed to act as the flange of the T-beam.

805—Bending Moments in Frames

(*a*) In monolithic frames or continuous construction the members should be designed to resist the bending moments and shears produced by the dead, live, and wind loads in accordance with methods of elastic frame analysis. For special conditions, such as centrifugal force, impact, braking and tractive forces in railway loadings, and for earthquakes or unequal settlement of the foundations, etc., the analysis should include the effect of these additional forces.

(*b*) For unusual building frames, continuous girder bridges, arches, or other types of statically indeterminate structures, rigorous methods of analysis are recommended.

(*c*) For ordinary building construction approximate methods of frame analysis are satisfactory.

(*d*) Regardless of the method of computing bending moments, all horizontal members of the frame should be designed to resist a positive moment near the center of the span not less than $0.04\ w\ l^2$.

806—Bending Moments in One-Way Slabs (Solid or Ribbed), Spans of Any Length or Loading

(*a*) Floor slabs over a series of spans should be designed as restrained by their continuity with each other. Restraint afforded by the supports themselves, unless approaching fixity, and except as specially provided in (*c*) below, may be disregarded. However, a negative moment of at least $0.04\ w\ l^2$ per foot of width should be provided for in the slab at the discontinuous end.

(*b*) It is recommended that bending moments be computed for the following arrangement of live load:

1. The maximum negative moment at the support for two adjacent spans loaded.
2. The maximum positive moment near the middle of a loaded span when adjacent spans are not loaded.
3. The resultant moment (positive or negative) near the middle of an unloaded span when adjacent spans are loaded.

(*c*) In computing the bending moment near the middle of unloaded spans, in accordance with (*b*) 3 above, the torsional resistance of the supporting beam may be considered to restrain the rotation of the support to the

extent that adjacent spans may be assumed loaded with only one-half their specified live load.

(*d*) For proportioning the sections of slabs or ribs the negative bending moments may be computed at the face of the supports.

(*e*) In Appendix 2 is given a general method for computing moments at the center of the supports which can be applied to the assumptions of this section. The positive moments at mid-span can be obtained by the ordinary methods of statics, but the resisting moment provided should not be less than required by 805(*d*).

807—Bending Moments in One-Way Slabs (Solid or Ribbed) of Equal Spans

(*a*) For the special case of equal span lengths, equal stiffness, and uniform loading, the requirements in Sect. 806(*a*), (*b*), and (*c*) are substantially fulfilled by the coefficients given in Appendix 3.

808—Bending Moments in Beams and Girders

(*a*) The positive and negative bending moments in beams and girders designed to be built monolithically with columns, beams, or walls, should be computed in accordance with the theory of elastic frames.

(*b*) In building construction, horizontal members of the frame should be designed as being restrained by their continuity with each other and by supporting and other members connecting at the joints. Where no great irregularities of span, story-height, or loading are involved the general method given in Appendix 2 may be used for computing the moment at the centerline of supports. In the case of beams framing into a girder, the restraint due to the torsional resistance afforded by the girder may be assumed as equal to that which would be furnished by a column having a stiffness factor equal to one-half the average stiffness factor of the beams framing into the girder.

(*c*) Bending moments should be computed for the arrangement of live load recommended in Sect. 803(*a*).

(*d*) The moment at the face of a support may be used for proportioning the member. This moment may be obtained approximately from the moment at the centerline by subtracting a quantity $Va/3$, where V is the shear at the face of the support and a is the width of the support.

(*e*) Positive moments may be computed by the ordinary methods of statics, but the resisting moment provided should not be less than $0.04\ w\ l^2$.

Two-Way Slabs with Supports on Four Sides

809—General

(*a*) These recommendations are intended to apply to slabs (solid or ribbed), isolated or continuous, supported on all four sides by walls or beams, in either case built monolithically with the slabs. The recommended coefficients, as in the case of the design provisions for flat slabs, are based partly on analysis and partly on test data. (In general, the coefficients and methods

given in these recommendations are based upon the coefficients proposed by H. M. Westergaard,[5] M. Am. Soc. C. E. Some modifications of these coefficients have been made and the series extended to include cases not covered by Dean Westergaard. In making these modifications and extensions full consideration has been given to the results of available test data.) The analysis indicates that for square panels the moments may be substantially less than those determined on the basis of independent prismatic beam elements. Similar decrease is considered to hold for other than square panels but at reducing percentages until a ratio of short to long span of 0.5 is reached. For this and all lesser ratios the entire distributed load (except that in the column strips) is assumed to be carried in the short direction of the panel. Available test data indicate that these assumptions are justified.

(*b*) Available data also indicate that when two-way slabs are cast monolithically with supporting beams, the distribution and the numerical values for bending moments in slabs with one or more discontinuous edges do not differ widely from those of interior panels. However, these data are rather limited, but the moment coefficients recommended in Table 5 for the slabs with discontinuous edges are conservative and in general agreement with accepted theoretical considerations and general practice.

(*c*) In the special case of slabs discontinuous at 4 edges (isolated panels, case 5, Table 5), the coefficients may be assumed to apply also to slabs which are built into masonry walls, provided the weight of masonry above the slab is sufficient to restrain the slab properly at the edges. The average parapet wall is probably lacking in this respect.

810—Limitations and Notations

(*a*) The recommended moment coefficients in Table 5, Sect. 811, are intended to apply to panels fully loaded with a uniformly distributed load. For values of m intermediate between those shown in Table 5, interpolated values of the moment coefficients may be used. For values of m less than 0.5 the coefficients given for this ratio should be used.

(*b*) Panels are considered as being divided into middle strips and column strips as in flat slabs (see Sect. 834(*a*)). For panels in which the ratio m is less than 0.5 the middle strip in the short direction of the panel should have a width equal to the difference between the long and short spans, the remaining area representing the two column strips.

(*c*) *Notation.*—Span lengths of panels should be taken as the center-to-center distance between supports or as the clear span plus twice the thickness of the slabs, whichever value is the smaller.

$$S = \text{short span as defined above}$$

$$m = \text{ratio } \frac{\text{short span}}{\text{long span}}$$

$$w = \text{load per unit area}$$

[5] "Formulas for the Design of Rectangular Floor Slabs and Supporting Girders," by H. M. Westergaard; Proceedings, American Concrete Institute, 1926, p. 26.

(*d*) *Principal Design Sections.*—The critical sections for moment calculations are referred to as principal design sections and are located as follows:

For negative moment, along the edges of the panel at the faces of the supporting beams.
For positive moment, along the center lines of the panels.

811—Bending Moment Coefficients

(*a*) *Middle Strips.*—In Table 5 are given the bending moment coefficients for the middle strips for both short and long spans for varying values of the ratio m of short to long span. These coefficients, when multiplied by $w\,S^2$ give the bending moment per unit width of slab. The basis of this table is a maximum negative moment of $0.033\,w\,S^2$ per unit width in the middle strip for square interior panels. The coefficients for other than square panels and for panels with one or more edges discontinuous are based on the following modifications of this basic moment for the square interior panel:

1. Bending moments in the short span increase as the ratio m decreases.
2. Bending moments in the short span increase successively with the introduction of one or more discontinuous edges, the increase being independent of the position of the discontinuous edges.
3. Bending moments for the long span for all values of m are equal to the bending moments in a square panel having sides equal to the short span.
4. Negative moments at discontinuous edges are taken as equal to ½ of the corresponding moment at the continuous edge.
5. Positive moments at the center are taken as ¾ of the negative moment at the continuous edge.

(*b*) *Column Strips.*—For moments in the column strips, coefficients two-thirds of those given in Table 5 for the corresponding moments in the middle strip should be used. In determining the spacing of the reinforcement for the column strip, the moment at any section may be assumed to vary from a maximum at the edge of the middle strip to a minimum at the edge of the panel, but the average should be that computed from the coefficient as given herein.

(*c*) *Corner Reinforcement.*—Experience and theoretical considerations have shown the need for reinforcement at exterior corners to prevent cracks in diagonal directions. The effective amount of such reinforcement per foot of width should be equal to that for the positive moment in the middle strip. This is required in both the top and bottom face of the slab. By the effective amount of the steel is meant the normal area multiplied by the sine of the angle which the bar makes with the critical section. In the top of the slab the critical section is perpendicular to the diagonal; in the bottom of the slab it is parallel to the diagonal.

812—Distribution of Unequal Negative Moments at Supports

(*a*) In applying the moment coefficients of Table 5 to adjacent panels of varying dimensions and unequal loading, the negative moments on either side of a supporting beam may differ materially. Under these conditions

TABLE 5.—BENDING MOMENT COEFFICIENTS FOR RECTANGULAR PANELS SUPPORTED ON FOUR SIDES AND BUILT MONOLITHICALLY WITH SUPPORTS

(Coefficients are for moments in middle strips.)

Moments	Short Span						Long Span All Values of *m*
	Values of *m*						
	1.0	0.9	0.8	0.7	0.6	0.5 and less	
Case 1—Interior Panels							
Negative Moment at							
Continuous edge	0.033	0.040	0.048	0.055	0.063	0.083	0.033
Discontinuous edge	....	....	....	....	....	....	....
Positive Moment at Midspan	0.025	0.030	0.036	0.041	0.047	0.062	0.025
Case 2—One Edge Discontinuous							
Negative Moment at							
Continuous edge	0.041	0.048	0.055	0.062	0.069	0.085	0.041
Discontinuous edge	0.021	0.024	0.027	0.031	0.035	0.042	0.021
Positive Moment at Midspan	0.031	0.036	0.041	0.047	0.052	0.064	0.031
Case 3—Two Edges Discontinuous							
Negative Moment at							
Continuous edge	0.049	0.057	0.064	0.071	0.078	0.090	0.049
Discontinuous edge	0.025	0.028	0.032	0.036	0.039	0.045	0.025
Positive Moment at Midspan	0.037	0.043	0.048	0.054	0.059	0.068	0.037
Case 4—Three Edges Discontinuous							
Negative Moment at							
Continuous edge	0.058	0.066	0.074	0.082	0.090	0.098	0.058
Discontinuous edge	0.029	0.033	0.037	0.041	0.045	0.049	0.029
Positive Moment at Midspan	0.044	0.050	0.056	0.062	0.068	0.074	0.044
Case 5—Four Edges Discontinuous							
Negative Moment at							
Continuous edge	....	....	....	....	....	....	....
Discontinuous edge	0.033	0.038	0.043	0.047	0.053	0.055	0.033
Positive Moment at Midspan	0.050	0.057	0.064	0.072	0.080	0.083	0.050

These coefficients, when multiplied by $w S^2$, give the moment per foot of width. w = load per sq ft; S = short span as defined in Sect. 810(*c*).
Note that $w S^2$ is the multiplier for both short and long span moments.

some modification of the moments should be made, based on the relative rigidity of the slabs and the resistance offered by the support. For this purpose the assumption that the supporting beams offer a restraint equivalent to the average of the stiffness factors of the adjacent slabs may be used in a manner similar to that given in Sect. 808(*b*) for beams framing into girders. On this basis two-thirds of the unbalanced negative moment should be distributed to the two spans in proportion to their respective stiffness factors.

(*b*) Where conditions are such as to require modification of the support moments, as given in (*a*) above, the corresponding midspan moments may be obtained by the procedure ordinarily followed for continuous beams.

For this purpose, the unadjusted negative moments obtained from Table 5, considered as equivalent to fixed end moments, may be multiplied by 1½ to obtain the simple span moments. The midspan moment then would be equal to the average adjusted end moments less 1½ times the unadjusted end moments. The coefficients in Table 5 for positive moments at midspan are sufficiently conservative to cover ordinary cases. However, where large adjustment of the support moments is required, the midspan moments should be investigated.

813—Shear in Slabs

The shearing stresses in the slab should be computed on the assumption that the load is distributed to the supporting beams in accordance with Sect. 815.

814—Minimum Slab Thickness

The slab thickness should not be less than 4 inches, nor less than the value computed by the following formula:

$$t = \left[S + \frac{S}{m} - \frac{N}{10} \right] \frac{1}{72} \sqrt[3]{\frac{2{,}500}{f'_c}}$$

where t = Slab thickness in inches
S (in inches) and m as in Sect. 810(c)
N = Total length in inches of slab periphery which is continuous with adjacent slabs.

815—Loads and Bending Moments in Supporting Beams

(a) *Distribution of Load.*—The loads on the supporting beams for a two-way rectangular panel may be assumed as the uniformly distributed load within the tributary areas of the panel bounded by the intersection of 45° lines from the corners with the median line of the panel parallel to the long side.

(b) *Total Load and Shear.*—On the basis of the load distribution in (a) above, the total loads on the short and long span beams due to one loaded panel are given by the following formulas, respectively.

$$W_S = \frac{w\,S^2}{4}$$

$$W_L = \frac{w\,S^2}{4}\left[\frac{2 - m}{m}\right]$$

The end shears may be obtained from the above loads by the usual modifications of the reactions for any difference in end moments.

(c) *Bending Moments.*—The bending moments may be obtained for the load distribution assumed by the methods of mechanics appropriate to the conditions of support, or they may be determined approximately by transforming the load on the beams to equivalent uniform load per lineal foot of

beam as follows:

$$\text{For the short span, } = \frac{w\,S}{3}$$

$$\text{For the long span, } = \frac{w\,S}{3}\left[\frac{3 - m^2}{2}\right]$$

DIAGONAL TENSION AND SHEAR

816—General

(*a*) For homogeneous beams the diagonal tensile stress is given by well-known formulas as a combined stress. This stress is a function of the shearing and the flexural stress at any point in the beam. Where the flexural stress is zero, as for example, at the neutral surface, at points of inflection, or at the supports of simple beams, the diagonal tensile stress is equal to the shearing stress and is inclined at an angle of 45° with the neutral surface.

(*b*) Because of the composite character of reinforced concrete beams the action of reinforcement in resisting diagonal tension is not susceptible of exact analysis. The design of web reinforcement is therefore based on empirical or modified rational methods. These methods were developed by observation of existing structures and from test results that do not apply with certainty to new and untested arrangements of reinforcement.

(*c*) However, when ordinary web reinforcement is used, such as vertical stirrups, bent-up longitudinal bars, or the combination of these, the resistance to diagonal tension or shear is greatly increased. This is especially true if adequate bond resistance is provided, either in the form of low bond stress or effective anchorage of the reinforcement. The importance of bond resistance is such that high working stresses in shear are only permitted when all the reinforcement is properly anchored.

(*d*) In view of available data the following assumptions are recommended as a proper basis for design.

1. The vertical shear is a measure of diagonal tension in the web of beams.
2. The effectiveness of web reinforcement is measured by its projection on a plane inclined at 45° with the neutral surface.
3. Web reinforcement provides for the shear in excess of that permitted in beams with longitudinal reinforcement only.

817—Shear and Diagonal Tension in Beams

(*a*) Beams (including ribs and other members subject to bending) should be designed to resist the diagonal tension in their webs without exceeding the stresses prescribed in Sect. 878. The critical section for diagonal tension should be taken at the face of the supports.

(*b*) For purposes of design, diagonal tension is assumed to be directed at an angle of 45° with the axis of the beam, and its intensity is measured by the unit shear as computed by the formula:

$$v = \frac{V}{b\,j\,d} \qquad \text{(1)}$$

where V = total external vertical shear at the section
jd = moment arm of the internal force couple
b = width of the beam

For beams of I- or T-section, b is the width of the concrete web or stem. In case the sides of the web are not parallel the average width may be used, provided it does not exceed the minimum width by more than 20%.

(*c*) In ribbed tile construction where fillers are used consisting of burned clay or concrete tile having a net compressive strength in the shells at least equal to that of the concrete in the ribs, and so placed that the joints in alternate rows are staggered, the shells of the fillers in contact with the ribs may be used in computing the shearing stress at any section of the rib.

(*d*) Where the shearing stress as computed by Formula (1) exceeds the stress (v_c) permitted for an unreinforced web (Sect. 878), web reinforcement should be provided at all sections for the amount of shear exceeding that allowed for webs without reinforcement.

(*e*) Where the shearing stress exceeds $0.06f'_c$ the web reinforcement should be designed to carry the entire shear.

818—Types of Web Reinforcement in Beams

Web reinforcement may consist of vertical or inclined stirrups and bent-up longitudinal reinforcement or combinations thereof. Bars inclined at an angle less than 15° with the axis of the beam shall not be considered as web reinforcement. When v exceeds $0.06f'_c$ bent-up bars or inclined stirrups should be provided in addition to vertical stirrups.

819—Design of Web Reinforcement in Beams

(*a*) Web reinforcement is considered effective only when anchored at both ends according to Sect. 828 and 830.

(*b*) Web reinforcement, whether vertical or inclined, is assumed to contribute to diagonal tensile resistance only the component of its total resistance that lies in a direction of 45° with the axis of the beam.

The stirrup spacing (or length of beam over which the bar is effective) is given by the formula:

$$s = \frac{A_v f_s j d (\cos x + \sin x)}{V'} \qquad (2)$$

wherein: s = the horizontal distance along the axis of the beam between bars;
x = the angle the bars make with the axis of the beam;
A_v = the total normal cross-sectional area of web reinforcement in any plane;
V' = the total external vertical shear in excess of that allocated to the unreinforced web according to Sect. 817(*d*) and (*e*).

For vertical stirrups this becomes:

$$s = \frac{A_v f_s j d}{V'} \qquad (3)$$

and for stirrups or bars inclined at 45°:

$$s = \frac{A_v f_s j d}{0.7 V'} \quad \text{(4)}$$

wherein f_s = 16,000 lb per sq in. or less, regardless of the grade of steel used. Where bars are bent up in a single plane the effective length (s) as given by Formula (2) is to be measured, one-half each way from the bar at the mid-depth of the beam and should not exceed $\frac{3}{4}d$.

(*c*) Web reinforcement should be so spaced that every 45° line extending from the mid-depth of the beam (downward and towards the nearest support) to the longitudinal tension bars should be intersected by at least one line of web reinforcement. If the shearing stress exceeds $0.06 f'_c$, every such line should be intersected by at least two such lines of web reinforcement.

(*d*) Where more than one type of reinforcement is used to reinforce the same portion of the web, the total shearing resistance of this portion of the web is assumed to be the sum of the shearing resistances computed for the various types separately.

820—Shear and Diagonal Tension in Flat Slabs

(*a*) The shearing stress on a vertical section which lies at a distance equal to the effective depth of the slab beyond the edge of the column capital (or bracket) and parallel or concentric with it, should not exceed the following values when computed by Formula (1):

1. $0.03 f'_c$ when at least 50% of the total negative reinforcement of the column strip passes through the section,
2. $0.025 f'_c$ when 25% of the total negative reinforcement of the column strip passes through the section,
3. For intermediate percentages, proportional values of the shearing stress may be used.

(*b*) The shearing stress on a vertical section which lies at a distance equal to the effective depth of the slab beyond the edge of the drop panel and parallel with it should not exceed $0.03 f'_c$ when computed by Formula (1). At least 50% of the cross-sectional area of the negative reinforcement in the column strip should be placed within the strip directly above the drop panel. (See Sect. 843.)

821—Shear and Diagonal Tension in Footings

(*a*) The shearing stress as computed by Formula (1) on the critical sections (as defined in Sect. 866(*c*) and (*d*)) should not exceed $0.02 f'_c$ for footings reinforced with straight bars only, nor $0.03 f'_c$ where the reinforcement is adequately anchored by hooks or otherwise as described in Sect. 827 and 828.

(*b*) For combined footings and raft foundations the shearing stresses and web reinforcement for beam elements may be treated the same as for flexural members described in Sect. 818 and 819 except that the shearing stress should not exceed $0.06 f'_c$.

822—Wedge-Shaped Beams

In beams of variable depth the resultant internal shear at any section is increased or decreased by the vertical components of the inclined stresses (tension or compression) as described in Sect. 825.

BOND AND ANCHORAGE

823—General

(*a*) The theory of reinforced concrete is based on the assumption that stress is transmitted from one material to the other by bond. Consequently, all members of the structure should be so designed that stress transfer is accomplished without exceeding recommended allowable bond values.

(*b*) In members subject to direct stress, also in end anchorage of flexural reinforcement, the bond stress is assumed to be uniformly distributed over the embedded surface of the bar.

(*c*) In members subject to bending, the bond stress varies in proportion to the amount of external shear and is generally a maximum in the region near the supports. In order to maintain normal beam action and structural integrity of the member, slipping or appreciable movement of the reinforcement must be prevented. End anchorage is effective in increasing resistance to slipping and therefore serves as an added factor of safety against failure by diagonal tension.

824—Bond Stresses in Beams of Uniform Depth

(*a*) In beams in which tensile reinforcement is parallel to the compressive face, that is, excluding wedge-shaped beams, the bond stress, u, is given by the formula:

$$u = \frac{V}{\Sigma o j d} \qquad (5)$$

wherein Σo = the sum of the perimeters of all the bars at the section; and, V and $j d$ are as in Sect. 817(*b*). (It is recognized that when end anchorage is used the assumptions upon which Formula (5) are based may not strictly apply. However, the committee believes that the use of Formula (5) with the higher allowable bond stresses permitted in Sect. 827 for end anchorage is amply supported by test data.)

(*b*) In applying Formula (5) to any section of a beam in which the reinforcement includes bent bars, those portions of bars which are within a distance of one-third the effective depth of the beam from the main longitudinal reinforcement may be counted as contributing to bond resistance.

825—Wedge-Shaped Beams

(*a*) In beams of variable depth the resultant internal shear at any section is increased or decreased by the vertical components of the inclined stresses (tension or compression) depending on whether they agree or are opposite in sign to the direction of the external shear. The bond stress is obtained by

substituting for V in Formula (5) the value V_1, given by the following formula:

$$V_1 = V \pm \frac{M}{d} (\tan c + \tan t) \quad \text{(5a)}$$

The negative sign is to be used when the depth of the beam increases in the direction of increasing bending moment and the positive sign when the depth decreases as the moment increases.

wherein M = bending moment;
d = depth of beam at the section; and
c and t = the angles, respectively, that beam faces make with a direction normal to the direction of the external shear.

(*b*) In beams of this type including sloped footings, tapered brackets, and cantilever beams, bond stresses may be excessive. This is particularly true of tapered cantilever beams loaded at the unsupported end. These and similar cases may require end anchorage.

826—End Anchorage of Reinforcement

(*a*) In beams where the bond stress as computed by Formula (5) exceeds the allowable normal working stress, the use of end anchorage permits some form of redistribution of stress to take place. Without attempting to rationalize the precise character and action of anchorage, reliance is placed on tests which indicate that end anchorage is equivalent to increased bond resistance. Consequently, with effective end anchorage a somewhat higher bond stress may be allowed than is permitted for unanchored reinforcement.

(*b*) Since resistance to diagonal tension failure is primarily a function of bond resistance, increased shearing stresses are also permissible when special precautions are taken to prevent slipping of the reinforcement.

827—Unit Stresses with End Anchorage for Beams

The increased shearing and bond stresses recommended in Sect. 878 are based on the use of end anchorage, in accordance with Sect. 828, in addition to the ordinary extension requirements outlined in Sect. 829. Where these higher stresses are used all of the longitudinal bars should be provided with end anchorage, except those which are bent across the web at an angle not less than 15° with the neutral plane and made continuous with the reinforcement along the opposite face of the beam.

828—Allowable Capacity of End Anchorage—Hooks

Anchorage, transmitting direct stress, tension or compression, within the limits of allowable normal bond stress is assumed to provide for the full working stress in the bar by uniform distribution of bond stress over the embedded surface. End anchorage, however, being a device to provide for increased bond and shearing stress should be limited to some definite amount. It is recommended that end anchorage be assumed to develop a maximum stress of 10,000 lb per sq in. in the bar so anchored. End anchorage may be an extension of the bar or a hook. In either case the additional length of bar

should provide the needed anchorage by normal bond stress, assumed to be uniformly distributed over the additional embedded surface. A properly dimensioned hook is one in which the bar is bent in a full semicircle, with a radius of bend not less than three diameters, plus an extension at the free end of at least four bar diameters. Right angle or other abrupt bends, which do not engage a structural steel member, are not to be considered as anchorage unless the radius of the bend is at least 4 bar diameters and the total length from beginning of bend to the free end of the bar is at least 16 bar diameters.

829—Extension of Reinforcement

(*a*) To provide for contingencies arising from unanticipated distribution of loads, yielding of supports, shifting of points of inflection, or other lack of agreement with assumed conditions governing the design of elastic structures, it is recommended that the reinforcement be extended at the supports and at other points between the supports as indicated in (*b*) to (*f*) below. These paragraphs relate to ordinary anchorage and are the minimum requirements under which normal working stresses for bond or shear are permitted.

(*b*) Negative tensile reinforcement at the supported end of a restrained or cantilever beam or member of a "rigid frame" should be extended in or through the supporting member in such a manner as to develop the maximum tension in the bar with a bond stress not exceeding the normal working stress provided in Sect. 878.

(*c*) Between the supports of continuous or freely supported beams, every reinforcing bar should be extended at least 12 diameters, but not less than one-twentieth of the span length, beyond the point at which computations indicate it is no longer needed to resist stress.

(*d*) In simply supported beams and freely supported ends of continuous beams, at least *one-third* of the positive reinforcement should extend into the supports a distance sufficient to develop one-half the allowable stress in the bars.

(*e*) In restrained or continuous beams at least *one-fourth* of the positive reinforcement should extend into the supports and the remainder treated as provided in (*c*).

(*f*) In restrained or continuous beams at least *one-third* of the total reinforcement provided for negative moment should extend beyond the point of inflection a distance sufficient to develop one-half the allowable stress in the bars so extended. Negative steel not so extended should be treated as provided in (*c*).

830—Anchorage of Web Reinforcement

(*a*) The stress in a stirrup or other web reinforcement should not exceed the capacity of its anchorage in the upper or lower one-half of the effective depth of the beam.

(*b*) Web reinforcement which is provided by bending into an inclined position one or more bars of the main tensile reinforcement where not required for resistance to positive or negative bending, may be considered

completely anchored by continuity with the main tensile reinforcement, or by embedment of the requisite length in the upper or lower half of the beam, provided at least one-half of such embedment is as close to the upper or lower surface of the beam as the requirements of fire and rust protection allow. A hook placed close to the upper or lower surface of the beam may be substituted for a portion of such embedment.

(*c*) Stirrups should be anchored at both ends by one of the following methods, or by a combination thereof:

1. Rigid attachment, as by welding, to the main longitudinal reinforcement.
2. Bending around and closely in contact with a bar of the longitudinal reinforcement, in the form of a **U**-stirrup or hook.
3. A hook placed as close to the upper or lower surface of the beam as the requirements of fire and rust protection will allow. In estimating the capacity of this anchorage the stress developed by bond between mid-height of the beam and the center of bending of the hook may be added to the capacity of the hook.
4. An adequate length of embedment in the upper or lower one-half of the effective depth of the beam, whether straight or bent. Anchorage of this type alone should not be relied on for stirrups in cases where the shearing stress in the web exceeds that recommended for beams without end anchorage of the reinforcement. (See Sect. 878.)

FLAT SLABS

831—General

The design of flat slabs is based on generally accepted empirical methods. These methods have been developed partly by analysis and partly by tests on models, full size test panels, and on a wide range of completed structures. Accordingly, the special provisions relating to the design of flat slabs apply only where certain general limitations are observed.

832—Limitations

(*a*) These provisions apply to:

1. Concrete slabs, without beams or girders, built monolithically with the supporting columns. These slabs may be increased in thickness at the supports by the use of drop panels, or along the margins to form paneled ceilings.
2. A series of rectangular slabs of approximately uniform dimensions arranged in three or more rows of panels in each direction, and in which the ratio of length to width of panel does not exceed 1.33.
3. Slabs with drop panels having a length in each direction of approximately one-third of the panel length in that direction. Also to continuous drop panels that form paneled ceilings, in which the continuous drops have a width approximately one-third of the panel width.

4. Slabs with drop panels in which the total thickness of the slabs through the drops does not exceed one and one-half times the thickness of the slabs beyond the drops.

(*b*) Structures having a width of less than three rows of panels, or in which the adjacent panel dimensions vary by more than 15%, are outside the scope of these provisions and require special analysis.

833—Notation

The following notation applies to the design of flat slabs except when otherwise specifically stated:

M_o = Sum of the total positive and negative bending moments at the principal design sections in either direction, the sections being parallel to the margins of the panels.

c = Effective diameter in feet of a round column capital, at the underside of the slab or drop panel. No portion of the column capital should be considered effective which lies outside of the largest 90° cone that can be included within the outlines of the column capital. When a square, or other symmetrically shaped capital is used, c is the diameter of a circle whose area is equal to the area of the base of the largest 90° pyramid which can be included within the outlines of the column capital.

l = Span length, in feet, center to center of the columns along the panel margins, in the direction in which moments are computed.

l_1 = Span length, in feet, center to center of columns perpendicular to the direction of the span for which moments are computed.

w = Total dead and live load in lb per sq ft of loaded area.

d = Effective depth, in inches, of the slab at any point.

t_1 = Total thickness, in inches, of the slab with or without drops, at the boundary of the column capitals.

t_2 = Total thickness, in inches, of the slab beyond the boundary of the drop.

834—Panel Strips and Principal Design Sections

(*a*) A flat slab panel is considered as consisting of strips in each direction as follows:

A middle strip one-half panel in width, symmetrical about panel center line and extending through the panel in the direction in which moments are considered.

A column strip one-half panel in width occupying the two quarter-panel areas outside of the middle strip.

(*b*) The critical sections for moment calculations are referred to as principal design sections and are located as follows:

Sections for negative moment along the edges of the panel, on lines joining the column centers, except that they follow the perimeter of the column capital instead of passing through it.

Sections for positive moment along the center lines of the panel,

(*c*) In the two-way system it is assumed that the tensile stresses due to the moments in the various strips are resisted by the band of reinforcing bars located within the strip.

(*d*) In the four-way system, or any other system of reinforcement, in which a part or all of the reinforcement is not parallel to the direction of the span, it may be assumed that the tension due to bending moments at any section of a strip is resisted by the components, in the direction of the span, of all the reinforcement included within the boundary of the section under consideration.

(*e*) The width of the column head section for computing compression should be taken as the width of the drop or half the width of the panel ($0.5\, l_1$) where no drop is used.

835—Bending Moments in Rectangular Flat Slabs

(*a*) The total bending moment M_o, in the direction of either side of the panel, is divided between the sections of positive and negative moment, the basis of division depending on the size of columns, column capitals, and dimensions of the panels. For average conditions, approximately three-eighths of the total may be considered positive, and five-eighths negative moment. Slabs with drops are assumed to develop about 5% more negative moment than slabs of uniform thickness, and to have a corresponding decrease in the positive moment. Furthermore, the column strips are assumed to take 75 to 80% of the total negative moment and 50 to 56% of the total positive moment. The detail distribution of the total moment varies to a moderate extent depending on the system of reinforcement employed.

(*b*) *Total Bending Moment.*—For interior panels carrying an assumed uniformly distributed load the numerical sum of the positive and negative moments at the principal design sections in the direction of either side of a rectangular panel is given by the formula:

$$M_o = 0.09\,(l - \tfrac{2}{3}\,c)^2\, w\, l_1 \quad \ldots\ldots\ldots\ldots (6)$$

(*c*) *Distribution of Moments.*—For interior panels the distribution of the total moment M_o at the principal design sections is given in Table 6. This distribution agrees with the 1924 Joint Committee Report and with well-established requirements in this country, and is in close agreement with European practice.

836—Tolerances Applicable to Table 6

(*a*) The moment coefficients given in Table 6 may be varied by not more than 6%, provided the numerical sum of the positive and the negative moments at the principal design sections is not reduced.

(*b*) The ratio of reinforcement at any section of any band should not be less than 0.0025.

TABLE 6.—MOMENTS TO BE USED IN DESIGN OF FLAT SLABS FOR INTERIOR PANELS

Strip	Flat Slabs without Drops		Flat Slabs with Drops	
	Negative	Positive	Negative	Positive
	Slabs with Two-Way Reinforcement			
Column strip Middle strip	0.46 M_o 0.16 M_o	0.22 M_o 0.16 M_o	0.50 M_o 0.15 M_o	0.20 M_o 0.15 M_o
	Slabs with Four-Way Reinforcement			
Column strip Middle strip	0.50 M_o 0.10 M_o	0.20 M_o 0.20 M_o	0.54 M_o 0.08 M_o	0.19 M_o 0.19 M_o

837—Conditions of Restraint at Discontinuous Edges

The modifications of moments at discontinuous edges is based on the assumption that the slab is restrained by the supporting beam framed into columns of adequate rigidity. A column (or two columns one above the other) having a stiffness factor $\left[\frac{I}{h}\right]$ at least equal to 1½ times the stiffness factor of the slab $\left[\frac{I}{l}\right]$ may be assumed as adequate. The moment of inertia (I) of the slab section may be computed on the basis of a width equal to the column spacing and a depth equal to the slab thickness plus one-third the depth of the drop.

838—Moments in Discontinuous Panels

(*a*) In the case of end or side panels when the slab is not continuous on one edge or two adjacent edges, and in which the restraint at the discontinuous edge is as defined in Sect. 837, the bending moments as given in Table 6 should be modified as follows:

1. In the column strip the negative moment at the first interior column line and the positive moment at the center of the end panel should be increased 15% over the moments given for interior panels. For the middle strip the corresponding moments should be increased 30%.
2. At the wall or discontinuous edge the negative moments in the column strip and middle strips perpendicular to such edge may be reduced by 20% from those given for interior panels.
3. The half column strip adjacent and parallel to a supported edge may be designed for one-quarter of the full column strip moment given in Table 6.

(*b*) In slabs supported at the discontinuous edge by bearing walls, or where they are not restrained, the positive moments in the strips perpendicular to the wall should be increased 50%.

(*c*) When there is a beam or bearing wall at the center line of columns in the interior portion of a continuous flat slab, the negative moment in the middle strip perpendicular to the wall or beam should be increased 30%. The column strip adjacent and parallel to the wall may be treated as in (*a*)3, the remaining strips as in Table 6.

(*d*) At discontinuous edges the positive and negative reinforcement should extend to within 2 in. of the edge of the panel and be anchored in accordance with Sect. 828.

839—Thickness of Slab and Drop Panel

(*a*) The effective depth of the slab, with or without drop, is determined on the basis of negative bending moment and shear at the support and the allowable stresses. Since the negative moment is not uniform over the full width of the column strip, being higher at the center line that at the edges, the thickness determined on the basis of coefficients given in Table 6 and the allowable unit stress will result in excess compressive stress at the middle of the section. The thickness computed in this manner, therefore, is to be increased as provided in (*c*).

(*b*) In order to prevent undue deflection, and provide adequate depth where two or more bands of reinforcement are placed in layers at any section, the thickness at the center of the panel should not be less than the following limiting values, regardless of the values determined under (*c*).

1. Floor slabs with drop panels, 4½ in.
   Floor slabs without drop panels, 5 in.
2. Roof slabs with drop panels, 3½ in.
   Roof slabs without drop panels, 4 in.
3. Floor slabs: 2500-lb concrete
   a. End panels, 0.030 l
   b. Interior panels, 0.026 l
4. Roof slabs: 2500-lb concrete
   a. End spans, 0.025 l
   b. Interior spans, 0.023 l
5. For concrete having a 28-day compressive strength other than 2,500 lb per sq in., limitations 3 and 4 may be modified by multiplying the coefficients by $\sqrt[3]{\frac{2,500}{f'_c}}$

(*c*) *Interior Panels.*—The total thickness, t_1, of the slab with or without drops, may be determined from Formula (7) as follows:

$$t_1 = 1.2\,d + 1\tfrac{1}{2}\text{ in.} \qquad (7)$$

in which d = the effective depth of the slab, computed on the basis of the negative moments given in Table 6 and the assumed unit stresses governing the case under consideration (using balanced reinforcement).

For slabs with drops the width of the section resisting negative bending in the column strip should be limited to the width of the drop. For slabs without drops the full width of the column strip may be used.

The thickness, t_2, of the slab beyond the boundary of the drop should not be less than two-thirds of t_1.

(*d*) *Exterior Panel.*—For exterior panels the thickness of the slabs will vary according to the modifications in moment coefficients given in Sect. 838. (For end spans equal in length to interior spans, the increase in thickness is approximately 8%. A uniform slab thickness throughout the floor construction may, therefore, be obtained by making end panels 8% shorter than the interior spans.)

840—Beams in Flat Slab Construction

(*a*) *Marginal Beams Framing into Columns.*—Beams or thickened margins should be used at all discontinuous edges of flat slabs. They may be placed above or below the slab and should be cast monolithically with it. Such beams should be designed to carry, in addition to the loads directly upon them, a uniformly distributed load equal to one-fourth the total dead and live load for which the adjacent panel is designed.

(*b*) *Interior Beams.*—When an interior beam framing into columns is required for some special load, it should be designed as a T-beam to carry in addition to the special load a uniformly distributed load equal to one-quarter of the total load on the adjacent panels.

Where interior beams are supported by girders that frame into columns the whole panel should be framed to avoid uncertainty of moment and load distribution.

841—Column Capitals—Brackets—Drops

(*a*) The effective diameter of the column capital as defined in Sect. 833 should not be less than $0.20\,l$, where l = span length in square panels or the average span length in rectangular panels.

(*b*) *Brackets.*—Brackets on exterior columns may be substituted for capitals, provided the sloping face of the bracket makes an angle of not more than 45° with the face of the column, and is not less in width than the column. The value of c is twice the distance from center of column to the point where the bracket is 1½ in. in depth.

(*c*) *Drops.*—The drop should have a length in each direction not less than 1/3 of the panel length in that direction. If the shearing stresses at the edge of the drop exceed the allowable values given in Sect. 878, then the dimensions of the drop or the slab thickness outside the drop should be increased.

(*d*) If drop panels are used for interior columns they should also be used for wall columns.

842—Points of Inflection

For purposes of design the point of inflection in any line parallel to a panel edge in interior panels of symmetrical slabs without drop panels

should be assumed to be at a distance from the center of the span equal to 3/10 of the distance between two sections of critical negative moments; for slabs having drop panels, the coefficient should be 0.25. For end spans the position of the point of inflection is to be modified in accordance with the mechanics of restrained beams.

843—Arrangement of Reinforcement

The design should include adequate provision for securing the reinforcement in place so as to resist not only the critical moments but the moments at intermediate sections. Provision should be made for possible shifting of the point of inflection by carrying all bars in rectangular or diagonal directions, each side of a section of critical moment, either positive or negative, to points at least 1/15 of the span length beyond the assumed point of inflection as recommended in Sect. 842. Lapped splices should not be permitted at or near regions of maximum stress. At least 4/10 of all bars in each direction should be of such length and should be so placed as to provide reinforcement at two sections of critical negative moment and at the intermediate section of critical positive moment. Not less than 1/4 of the bars used for positive reinforcement in the column strip should extend into the drop not less than 20 diameters of the bar, or in case no drop is used, should extend to a point *not more than* 1/12 of the span length from the center line of the column or the support. Where drop panels are used, at least 1/2 of the cross-sectional area of the negative reinforcement in the column strip should be within the width of the strip directly above the drop panel.

844—Tensile Stress and Area of Steel Reinforcement

The tensile stress f_s in the steel and the total area A_s of the reinforcement for any critical section of design strips may be computed by the formula:

$$f_s = \frac{M_s}{A_s j d} \qquad (8)$$

wherein M_s = the moment given in Table 6 for column strip or for middle strip;

j = the usual ratio of the moment arm of the internal force couple to the effective depth;

d = effective depth of slab at the point in question; that is, the distance from the centroid of the tensile steel to the compressive face; and,

A_s = effective cross-sectional area of the reinforcement which crosses any of the principal design sections and meets the requirements of Sect. 834(*d*).

The stress so computed should not exceed the allowable working stress given in Sect. 878.

845—Compressive Stresses and Compression Reinforcement

Tests indicate that stresses are not uniformly distributed along the width of the column strip. This has been recognized in Sect. 839 where provision is made for thickness of slab. Cases occur, however, as in the end spans, where it is desirable to maintain the same slab thickness as for interior panels. This can be done by the introduction of compression reinforcement at the section of maximum negative moment.

846—Shearing Stresses in Flat Slabs

See Sect. 820.

847—Bond Stresses

See Sect. 823 to 830.

848—Openings in Flat Slabs

Openings of any size may be cut through a flat slab if provision is made for the total positive and negative resisting moments as required in Sect. 835 without exceeding the allowable stresses as given in Sect. 878.

849—Columns Supporting Flat Slabs

For requirements relating to bending moments in columns and limitation of column dimensions in connection with flat slab construction, see Sect. 859.

850—Special Construction

(*a*) The preceding recommendations for the design of flat slabs should not be applied to other than the two systems of reinforcement described, or to those systems where brackets or column capitals are omitted, unless analysis supported by adequate test data indicates that the stresses at the principal design and intermediate sections do not exceed the allowable unit stresses specified in Sect. 878.

(*b*) For structures having a width of one or two panels, or having panels of markedly different dimensions, an analysis should be made of the moments developed in both the slabs and the columns, and the requirements recommended in the preceding sections modified accordingly.

Reinforced Concrete Columns

851—General

(*a*) The following recommendations are based largely on the results of the extensive American Concrete Institute Column Investigation. Recognizing the presence of undesirable column shortening due to creep and shrinkage when small percentages of vertical steel are used, the minimum value is set at 1%; furthermore, a varying factor of safety is used, ranging, for axially loaded spiral columns, from about 3.6 for $p = 0.01$ to 2.75 for

$p = 0.08$. A similar variation from about 4.5 for $p = 0.01$ to 4.0 for $p = 0.04$ is used with tied columns.

(*b*) The formula for spiral columns is based upon recognition of the fact that the strength produced by spirals is accompanied by spalling of the column shell and excessive column shortening, hence the spiral is utilized only as a toughening element or an insurance against a sudden and complete collapse of the column. With spiral reinforcement provided, which is somewhat stronger than the protective shell, these two elements of strength (which cannot act simultaneously) become interchangeable, and justify the formula which uses gross area of column and omits any reference to the spiral. The formulas for tied and spiral columns are thus made identical, except that the latter is allowed 25% greater load-carrying capacity because of the presence of adequate spiral reinforcement to carry part of the load if the outer shell should spall.

(*c*) The design of long columns, both tied and spirally reinforced, is covered by a single equation based on the height-diameter ratio. With the test data available, no increase in accuracy would be attained by basing the slenderness ratio on the radius of gyration.

(*d*) The treatment of bending in columns is intended to correlate with the methods given in Sect. 805 for continuous beams and frames. Recent studies of creep indicate that the current analyses of combined bending and direct stress are not accurate, and that for cases in which the compressive stress governs the design, the theory of the uncracked concrete section applies without serious error. The permissible combined stresses in Sect. 860–861 are based on test data; they embody the fact that permissible bending stresses may be greater than axial stresses, and they are based on the conventional value of n, which produces the most severe of the probable conditions that the concrete may meet under sustained loading.

852—Limiting Dimensions

The following sections on reinforced concrete and composite columns (except Sect. 858) apply to a short column, for which the unsupported length is not greater than 10 times the least lateral dimension. When the unsupported length exceeds this value the design should be modified as shown in Sect. 858. Principal columns in buildings should have a minimum diameter or thickness of 10 in. Posts, bearing walls, piers, or mullions, that are not continuous from story to story should have a minimum diameter or thickness of 6 in.

853—Unsupported Length of Columns

(*a*) For purposes of determining the limiting dimensions of columns, the unsupported length of reinforced concrete columns should be taken as the clear distance between floor slabs with the following exceptions:

1. In flat slab construction, it should be the clear distance between the floor and the lower extremity of the capital.

2. In beam and slab construction, it should be the clear distance between the floor and the underside of the deepest beam framing into the column in each direction at the next higher floor level.

3. In columns restrained laterally by struts, it should be the clear distance between consecutive struts in each vertical plane; provided that to be an adequate support, two such struts should meet the column at approximately the same level and the angle between vertical planes through the struts should not vary more than 30° from a right angle. Such struts should be of adequate dimensions and anchorage to restrain the column against lateral deflection.

4. In columns restrained laterally by struts or beams, with brackets used at the junction, it should be the clear distance between the floor and the lower edge of the bracket, provided that the bracket width equals that of the beam or strut and is at least half that of the column, and provided further that the face of the bracket makes an angle with the face of the column of at least 45°.

(*b*) For all columns, that length should be considered which produces the greatest ratio of length to depth of section.

854—Spirally Reinforced Columns

(*a*) *Allowable Load.*—The maximum allowable axial load, P, on columns reinforced with longitudinal bars and closely spaced spirals enclosing a circular core is given by Formula (9):

$$P = 0.225 f'_c A_g + A_s f_s \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

wherein A_g = the overall or gross area of the column.

f'_c = compressive strength of the concrete, as found by tests of standard 6 by 12-in. control cylinders, as prescribed in Sect. 310.

f_s = nominal working stress in vertical column reinforcement, to be taken at 40% of the minimum specification value of the yield point; viz., 16,000 lb per sq in. for intermediate grade steel and 20,000 lb per sq in. for hard grade or rail steel. (Nominal working stresses for reinforcement of higher yield point may be established at 40% of the yield point stress, but not more than 30,000 lb per sq in., when the properties of such reinforcing steels have been definitely specified by standards of A.S.T.M. designation. If this is done, the lengths of splice required by (*c*) shall be increased accordingly.)

$A_s = p_g A_g$.

p_g = ratio of the effective cross-sectional area of vertical reinforcement to the gross area, A_g. (To be logical the area of the steel should be subtracted from A_g in Formula (9). However, the effect of the small area of concrete displaced by the reinforcement has been taken into consideration in arriving at the coefficient 0.225 applied to f'_c.)

(*b*) *Longitudinal Reinforcement—Amount and Spacing.*—The ratio p_g should not be less than 0.01 nor more than 0.08. The minimum number of bars should be six, and the minimum diameter of bar should be ⅝ in. The center-to-center spacing of bars within the periphery of the column core should not be less than 2½ times the diameter for round bars or 3 times the side dimension for square bars. The clear spacing between individual bars or between pairs of bars at lapped splices should not be less than 1½ in. or 1½ times the maximum size of the coarse aggregate used (see Sect. 504.)

(*c*) *Splices in Longitudinal Reinforcement.*—Where lapped splices in the column verticals are used, the minimum amount of lap should be as follows:

1. *For deformed bars.*—With concrete having a strength of 3,000 lb per sq in. or above, 24 diameters of bar of intermediate grade steel and 30 diameters of bar of hard grade steel. For bars of higher yield point, the amount of lap should be increased in proportion to the nominal working stress. When the concrete strengths are less than 3,000 lb per sq in. the amount of lap should be one-third greater than the values just given.
2. *For plain bars.*—The minimum amount of lap should be 25% greater than that specified for deformed bars.

Where changes in the cross section of a column occur, the longitudinal bars should be sloped for the full length of the column, or offset in a region where lateral support is afforded by concrete capital, floor slab, metal ties, or reinforcing spirals. Where bars are offset, the slope of the inclined portion from the axis of the column should not exceed 1 in 6 and the bars on each side of the offset should be parallel to the axis of the column.

Welded splices or other positive connections may be used instead of lapped splices. Welded splices should preferably be used in cases where the bar diameter exceeds 1¼ in. An approved welded splice should be defined as one in which the bars are butted and welded and that will develop in tension at least the yield point stress of the reinforcing steel used.

(*d*) *Spiral Reinforcement.*—The ratio of spiral reinforcement, p', should not be less than the value given by Formula (10)

$$p' = 0.45\left[\frac{A_g}{A_c} - 1\right]\frac{f'_c}{f'_s} \qquad (10)$$

wherein p' = ratio of volume of spiral reinforcement to the volume of the concrete core (out to out of spirals).

A_g/A_c = ratio of gross area to core area of column.

f'_s = useful limit stress of spiral reinforcement to be taken as 40,000 lb per sq in. for hot rolled rod of intermediate grade, 50,000 lb per sq in. for hard grade and 60,000 lb per sq in. for cold drawn wire.

Spiral reinforcement should consist of evenly spaced continuous spirals held firmly in place and true to line by at least three vertical spacer bars. For columns up to 18-in. core diameter, the minimum diameter of spiral bars should be ¼ in. For columns larger than 18-in. core diameter, the minimum diameter of spiral bars should be ⅜ in. Anchorage of spiral reinforcement should be provided by 1½ extra turns of spiral rod or wire at each end of the spiral unit. Splices, where necessary, should be made in spiral rod or wire by welding or by a lap of 1½ turns. The center-to-center spacing of the spirals should not exceed one-sixth of the core diameter. The clear spacing between spirals should not exceed 3 in. nor be less than 1⅜ in. or 1½ times the maximum size of coarse aggregate used. The column reinforcement should be protected everywhere by a covering of concrete cast monolithically with the core, for which the thickness should not be less than 1½ in. nor less than 1½ times the maximum size of the coarse aggregate, nor should it be less than required by the fire protection and weathering provisions of Sect. 505 and 506. The reinforcing spiral should extend from the floor level in any story to the level of the lowest horizontal reinforcement in the slab, drop panel, or beam above. In a column with a capital, it should extend to the plane at which the sectional area of the capital is twice that of the column.

(e) *Limits of Column Section.*—For columns built monolithically with concrete walls or piers, the outer boundaries of the column section should be taken as a circle 1½ in. outside the column spiral or as a square the sides of which are 1½ in. outside the spiral. In case two or more spirals are used in such a column the outer boundary should be taken as a rectangle the sides of which are at any point at least 1½ in. outside of the spirals. For these types of spirally reinforced columns the value of A_g thus defined should be used in both Formulas (9) and (10).

(f) *Equivalent Circular Columns.*—As an exception to the general procedure of utilizing the full gross area of the column section, it should be permissible to design a circular column and to build it with a square, octagonal, or other shaped section of the same least lateral dimension. In such case, the allowable load, the gross area considered, and the required percentages of reinforcement should be taken as those of the circular column.

855—Tied Columns

(a) *Allowable Load.*—The maximum allowable axial load on columns reinforced with longitudinal bars and separate lateral ties should be 80% of that given by Formula (9). The ratio, p_g, to be considered in tied columns should not be less than 0.01 nor more than 0.04. The longitudinal reinforcement should consist of at least four bars, of minimum diameter of ⅝ in. placed with a clear distance from the column face of not less than 1½ in. plus the thickness of the tie, provided that when nearer a corner than 4 in. this covering shall be increased to 2 in. Splices in reinforcing bars shall be made as described in Sect. 854(c).

(*b*) *Lateral Ties.*—Lateral ties should be at least ¼ in. in diameter and should be spaced apart not over 16 bar diameters, 48 tie diameters, or the least dimension of the column. When there are more than four vertical bars, additional ties should be provided so that every longitudinal bar is held firmly in its designed position.

(*c*) *Limits of Column Section.*—In a tied column which for architectural reasons has a larger cross section than required by considerations of loading, a reduced effective area A_g not less than one-half of the total area may be used in applying the provisions of Sect. 855(*a*), but the longitudinal reinforcement should be distributed over the full column section.

856—Composite Columns

(*a*) *Allowable Load.*—The allowable load on a composite column consisting of a structural steel or cast-iron column thoroughly encased in concrete reinforced with both longitudinal and spiral reinforcement, should not exceed that given by Formula (11):

$$P = 0.225\, A_c f'_c + f_s\, A_s + f_r\, A_r \qquad (11)$$

wherein A_c = net area of concrete section = $A_g - A_s - A_r$.

A_s = cross-sectional area of longitudinal bar reinforcement.

A_r = cross-sectional area of the steel or cast-iron core.

f_r = allowable unit stress in metal core, not to exceed 16,000 lb per sq in. for a steel core; or 10,000 lb per sq in. for a cast-iron core.

The remaining notation is that of Sect. 854.

(*b*) *Details of Metal Core and Reinforcement.*—The cross-sectional area of the metal core should not exceed 20% of the gross area of the column. If a hollow metal core is used it should be filled with concrete. The amounts of longitudinal and spiral reinforcement and the requirements as to spacing of bars, details of splices, and thickness of protective shell outside the spiral should conform to the limiting values specified in Sect. 854(*b*), (*c*), and (*d*). A clearance of at least 3 in. should be maintained between the spiral and the metal core at all points except that when the core consists of a structural steel H-column, the minimum clearance may be reduced to 2 in.

(*c*) *Splices and Connections.*—Metal cores in composite columns shall be accurately milled at splices and positive provision shall be made for alignment of one core above another. Transfer of loads to the metal core should be provided for by the use of bearing members such as billets, brackets, or other positive connections; these should be provided at the top of the metal core and at intermediate floor levels where required. Ample section of concrete and continuity of reinforcement should be provided at the junction with beams and girders. The column as a whole should satisfy the requirements of Formula (11) at every section; in addition to this, the reinforced concrete portion should be designed to carry, in accordance with Formula (9), all floor loads brought onto the column at levels between the

metal brackets or connections. In applying Formula (9) to a hollow core filled with concrete, the area of the concrete within the core should not be included in the area defined as A_g. At the column base, provision should be made to transfer the load to the footing at safe unit stresses in accordance with Sect. 870. The base of the metal core should be designed to transfer the load from the entire composite column to the footing, or it may be designed to transfer the load from the metal section only, provided it is so placed in the pier or pedestal as to leave ample section of concrete above the base for the transfer of load from the reinforced concrete section of the column by means of bond on the vertical reinforcement and by direct compression on the concrete.

(*d*) *Allowable Load on Bare Metal Core.*—The metal cores of composite columns should be designed to carry safely any construction or other loads to be placed upon them prior to their encasement in concrete.

857—Combination and Pipe Columns

(*a*) *Combination Columns; Steel Columns Encased in Concrete.*—The allowable load on a structural steel column which is encased in concrete at least 2½ in. thick over all metal (except rivet heads) reinforced as hereinafter required, should be computed by Formula (12):

$$P = A_r f'_r \left[1 + \frac{A_c}{100\,A_r}\right] \qquad (12)$$

wherein A_r = cross-sectional area of steel column.

f'_r = allowable stress for unencased steel column.

A_c = total area of concrete section, $= A_g - A_r$.

The concrete used should develop a compressive strength, f'_c, of at least 2,000 lb per sq in. when tested according to the provisions of Sect. 310. The concrete should be reinforced by welded wire mesh having wire not smaller than No. 10 gage, spaced in the vertical direction not more than 4 in., and in the horizontal direction not more than 8 in. This mesh should extend entirely around the column at a distance of 1 in. inside the outer concrete surface and should be lap-spliced at least 40 wire diameters and wired at the splice.

Special brackets should be used to receive the entire floor load at each floor level. The steel column should be designed to carry safely any construction or other loads to be placed upon it prior to its encasement in concrete.

(*b*) *Pipe Columns.*—The allowable load on columns consisting of steel pipe filled with concrete should not exceed that given by Formula (13).

$$P = 0.225\,f'_c\,A_c + f'_r\,A_r \qquad (13)$$

The value of f'_r should be that given by Formula (14).

$$f'_r = \left[18{,}000 - 70\,\frac{h}{R}\right] F \qquad (14)$$

wherein f'_r = allowable stress in the steel pipe section.
h = unsupported length of column.
R = radius of gyration of steel pipe section.

$$F = \frac{\text{tensile yield point of pipe material}}{45{,}000}.$$

If the yield point is not known, the factor F shall be taken as 0.5.

If the concrete strength f'_c is not known it shall be assumed at 2,500 lb per sq in.

858—Long Columns

(*a*) The maximum allowable load P' on axially loaded reinforced concrete or composite columns having a length, h, greater than 10 times the least lateral dimension, d, is given by Formula (15):

$$P' = P\left[1.3 - 0.03\frac{h}{d}\right] \qquad (15)$$

wherein P = the allowable axial load on a short column as given by Formulas (9) and (11).

(*b*) The maximum allowable load P' on eccentrically loaded columns in which h/d exceeds 10 is also given by Formula (15) in which P is the allowable eccentrically applied load on a short column as determined by the provisions of Sect. 860–861. In long columns subjected to definite bending stresses, as determined in Sect. 859, the ratio h/d should not exceed 20.

859—Bending Moments in Columns

The bending moments in the columns of all reinforced concrete structures should be determined on the basis of loading conditions and restraint and should be provided for in the design. When the stiffness and strength of the columns are utilized to reduce moments in beams, girders, or slabs, as in the case of rigid frames in general, the need for recognizing column moments is obvious; in other forms of continuous construction where column moments are unavoidable, they should also be provided for in the design. In building frames, particular attention should be given to cases of unbalanced floor loads on both exterior and interior columns and of eccentric loading due to other causes. Wall columns should be designed to resist moments produced by: (*a*) loads on all floors of the building, (*b*) loads on a single exterior bay at two adjacent floor levels, or (*c*) loads on a single exterior bay at one floor level. Resistance to bending moments at any floor level should be provided by distributing the moment between the columns immediately above and below the given floor in proportion to their relative stiffnesses and conditions of restraint.

860—Combined Axial and Bending Stress

(*a*) In reinforced concrete columns subjected to bending moments, the recognized methods of analysis should be followed in calculating the stresses

due to combined axial load and bending. The maximum fiber stress in compression and (in the case of large eccentricities of loading) the tensile stress in the vertical bars will govern the design. The gross area of both spiral and tied columns should be used in the computations.

(*b*) For preliminary designs it will usually give satisfactory results to compute the combined fiber stress in compression on the basis of an uncracked section of the column using Formula (16). (This will result in a fairly accurate design if the eccentricity is less than ½ the overall column width, and the value of $p_g\, n$ is 0.3 or more.)

$$f_c = \frac{P}{A_g} \frac{\left[1 + \frac{e\,c}{R^2}\right]}{1 + (n-1)\,p_g} \qquad (16)$$

wherein e = eccentricity of resultant load, measured from the gravity axis.

c = distance from gravity axis to extreme fiber in compression.

R = radius of gyration of equivalent concrete section.

n = as given in Sect. 878.

Other terms are as in Sect. 854. The term $\frac{e\,c}{R^2}$ may be replaced by the value $\frac{6\,e}{t}$ for rectangular columns and $\frac{8\,e}{t}$ for round columns without appreciable error (t = overall depth of section). This design may then be analyzed by more accurate methods to insure that allowable stresses are not exceeded.

861—Allowable Combined Axial and Bending Stresses

(*a*) For spiral and tied columns, eccentrically loaded or otherwise subjected to combined axial compression and flexural stress, the maximum allowable compressive fiber stress, f_c, is given by Formula (17):

$$f_c = f_a \frac{1 + \frac{e\,c}{R^2}}{1 + C\frac{e\,c}{R^2}} \qquad (17)$$

wherein the notation is that of Sect. 854 and 860, and, in addition, f_a is the average allowable stress on an equivalent axially loaded concrete column, and C is the ratio of f_a to the allowable fiber stress for members in flexure. Thus,

$$f_a = \frac{0.225\, f'_c + f_s\, p_g}{1 + (n-1)\,p_g}$$

for spiral columns, and 0.8 of this value for tied columns:

$$C = \frac{f_a}{0.45\, f'_c}\,.$$

(*b*) The allowable tensile stress in the longitudinal reinforcement may equal that specified for flexural members, provided however that splices in the tensile steel at or near the section of maximum column moment are capable of developing fully the yield point strength of the reinforcement.

862—Wind or Earthquake Stresses

When columns are subject to wind or earthquake stresses in addition to combined axial load and bending, the column section need not be increased unless the allowable stress given by Formula (17) is exceeded by more than one-third.

Footings

863—General

These recommendations include the design of wall, isolated and combined footings, and raft foundations.

For purposes of design it is assumed that foundations may be divided into combinations of simple, continuous, or cantilever beams—statically determinate—and proportioned accordingly.

It is recommended that projecting portions of all footings, whether isolated or combined, be treated as simple cantilever beams. This differs from the practice of considering trapezoidal areas in computing bending moments, in that the moment of the forces over the entire area on one side of any section is included in the bending moment for that section. This provides a general method of computing cantilever moments in irregular as well as symmetrically shaped footings.

864—Unit Stresses

Footings should be designed to sustain the applied loads without exceeding the allowable working stresses given in Sect. 878. It should be noted that the allowable bond stress is reduced 25% in all tension regions requiring moment reinforcement in more than one direction. See also Sect. 821–827, and 830.

865—Calculation of Stresses

(*a*) The bending, shearing, and bond stresses in isolated or combined footings should be determined for the critical sections indicated in Sect. 866. For the projecting portion of a footing the bending moment at any section may be considered as the statical moment of the forces over the entire area of the footing on one side of a vertical plane passing through that section. In two-way isolated footings, tensile reinforcement should be determined on the basis of 85% of the moments thus computed; in one-way footings, such as wall footings, the full moment should be used.

(*b*) For isolated footings cast as a unit, the section resisting bending in any direction may be the full vertical section cut by the plane about which

bending moment is computed, except for the cases of sloped or stepped footings, as treated below.

In sloped footings the section resisting bending may be as defined above provided the slope of the top is not such as to require special treatment of the projecting cantilever as a wedge-shaped beam. A slope of 1 vertical to 2 horizontal may be considered as a satisfactory limit. The slope of the footing top need not be uniform, provided the limit of 1 to 2 is not exceeded at any point.

For stepped footings, cast as a unit, the section resisting bending should be limited to the lower block, or to the area falling within the boundaries of an imaginary sloped footing which meets the above requirements as to slope and which lies entirely within the stepped footing.

In isolated footings the reinforcement should be distributed over the entire width of the section.

(*c*) In case the reinforcement does not cross at right angles a section at which bending moment is computed, only the component normal to the section should be considered effective, that is, the normal cross-sectional area of the bar multiplied by the sine of the angle which the bar makes with the section.

866—Critical Sections

(*a*) The critical section for bending in a concrete footing which supports a concrete column, pedestal, or wall, should be taken at the face of the column, pedestal or wall. In the case of columns other than square or rectangular the critical section should be taken at the side of a concentric square of equivalent area. For footings under masonry walls where bond with the footings is reduced to friction value, the critical section should be assumed midway between the middle and the edge of the wall. For footings under metallic column bases the critical section should be assumed midway between the face of the column and the edge of the metallic base. The load may be considered as uniformly distributed over the column, pedestal, or wall, or metallic column base.

(*b*) The critical sections for bond should be taken at the same plane as those for bending, and the shear used for computing bond should be based on the same loading and section as for bending. Bond should also be investigated at planes where changes of section or of reinforcement occur.

(*c*) The critical section for diagonal tension in footings on soil should be considered as the concentric vertical section through the footing at a distance d from each face of the column, pedestal, or wall. This depth d should be measured from the top of the section to the plane of the centroid of longitudinal reinforcement.

(*d*) The critical section for diagonal tension for footings supported on piles should be considered as the concentric vertical section through the footing at a distance $d/2$ from each face of the column, pedestal, or wall, and any piles whose centers are at, or outside this section should be included in computing the shear.

(*e*) In sloped or stepped footings, analyses should be made of stresses at sections where the slope or depth changes outside the critical section as defined in (*a*), (*b*), (*c*), and (*d*) above.

867—Plain Concrete Footings

(*a*) In plain concrete footings the section should be computed as a monolithic section of the entire width and depth measured from a plane 2 in. above the bottom of the footing. The maximum tensile fiber stress in the concrete should not exceed 0.03 of the ultimate compressive strength of the concrete. The average shearing stress should not exceed 0.02 of the ultimate compressive strength of the concrete, computed on a concentric vertical section through the footing at a distance (d − 2 in.) from each face of the column, pedestal, or wall, excluding 2 in. of depth nearest the bottom.

(*b*) The area of the top of the footing should not be less than that given by Formula (18), Sect. 870.

868—Combined Footings

(*a*) For reinforced concrete columns, the critical section for transverse bending should be taken at the faces of the columns or pedestals. For footings under metallic column bases, the critical section should be assumed midway between the face of the column and the edge of the metallic base. The transverse reinforcement should be divided into groups proportionate in sectional area to the column loads. The transverse reinforcement at each column should be placed uniformly within a band having a width not greater than the width of the column plus twice the effective depth of the footing. Longitudinal reinforcement should be distributed over the whole width.

(*b*) The critical sections for diagonal tension in combined footings should be taken at the faces of the supported members for all beam elements and also for all projecting cantilevers.

869—Raft Foundation

A raft foundation should be designed as an inverted floor system.

870—Transfer of Stress at Base of Column

(*a*) The compressive stress in the longitudinal reinforcement at the base of the column should be transferred to a pedestal or to a footing by extending the bars into the pedestal or footing or by the use of dowels. There should be at least one dowel for each column bar, and the total sectional area of the dowels should be not less than the sectional area of the longitudinal reinforcement in the column. The dowels or column bars should extend into the column, and into the pedestal or footing the distance required to transfer to the concrete, by allowable bond stresses, their full working strength. Hooks should not be considered as adding to bond resistance in compression. In addition to the provision for the transference

of load by dowels there should be provided at the top of the footing or pedestal an area (A) which is equal to or greater than that given by the following formula:

$$A = \left[\frac{f_b}{0.25 f'_c}\right]^3 A' \qquad (18)$$

wherein f_b = allowable working stress on the concrete in the column.
A' = area of the column.
f'_c = ultimate compressive strength of the concrete in the supporting member.

In all cases the concrete in the supporting member should be of such quality that the ratio of f_b to $0.25 f'_c$ does not exceed $1\frac{1}{2}$.

(*b*) In sloped or stepped footings, A may be taken as the area of the uppermost horizontal surface of the footing or as the area of the lower base of the largest frustum of a pyramid or cone contained wholly within the footing and having for its upper base the loaded area A' and having side slopes of 1 vertical to 2 horizontal.

(*c*) Formula (18) may be applied to determine the area required at the top of the footing or pedestal under a metal base. In this case f_b is to be taken as the actual bearing stress over the loaded area, and the limitation given in (*a*) for the quality of concrete should apply.

871—Concentrically Loaded Pedestals and Pedestal Footings

Plain Concrete.—(*a*) The compressive stress on the gross area of a pedestal or the upper surface of a pedestal footing should not exceed $0.25 f'_c$ unless reinforcement is provided and the member is designed as a reinforced concrete column.

(*b*) The depth and width of a pedestal or pedestal footing should be determined by consideration of shear and bending stresses as outlined under plain concrete footings (Sect. 867). A pedestal footing supported directly on piles should have a mat of reinforcing, of cross-sectional area not less than 0.20 sq in. per ft in each direction, placed 3 in. above the top of the piles.

Retaining Walls

872—Investigation of Stability

(*a*) Retaining walls, both plain and reinforced concrete, should be designed to resist the pressures of the retained material including both dead and live load surcharge to which they may be subjected.

(*b*) The wall should be designed for stability against (1) overturning, (2) sliding, (3) maximum soil pressure, as well as for moment, shear, bond, and maximum pressure at sections of the wall at regular intervals of height.

873—Moments and Pressures

(*a*) The pressures and overturning moments exerted by the retained material and the surcharge thereon, if not determined experimentally,

should be determined by means of analysis conforming with accepted practice. (Where the source of filling material is known in advance, investigation should be made of its unit weight, its angle of internal friction under various conditions of saturation and height. Consideration should be given to possible hydrostatic pressure and the reduction of weight of the filling material due to buoyancy.)

(*b*) Where a retaining wall is subjected to the various pressures of different materials along its height, each height of wall should be analyzed for the filling material behind it, the material above each plane considered being computed as surcharge.

874—Foundation Pressures

Foundation pressures should be determined from the consideration of the location, magnitude, and direction of the resultant thrust at the base.

875—Allowable Unit Stresses and Critical Sections

(*a*) Retaining walls, including footings, both plain and reinforced, should be so designed that at no section or part of wall or footing should the allowable stresses for shear, bond, compression or tension as provided in Sect. 878 be exceeded.

(*b*) Critical sections in the various parts of the wall or footing should be taken as those recommended for beams, slabs, and footings.

876—Provisions for Stability

(*a*) For stability against sliding, resistance should be provided for at least twice the computed active horizontal thrust on the wall.

(*b*) For stability against overturning, the righting moment of the weight of the wall, fill, and other superimposed loads should be at least 50% greater than the overturning moment due to the thrust of the filling material together with that due to any dead load or live load surcharge. For walls resting on soils, the resultant pressure at the base should fall within the middle third of the base; and where vibration occurs, near the center of the base, to reduce unequal settlement.

(*c*) The maximum soil pressure resulting from the maximum thrust at the bottom of the footing inclusive of the effect of eccentricity of such thrust should not be greater than the permissible bearing power of the soil which supports the wall. Consideration should be given to a possible redistribution of the soil pressure due to such eccentricity and to the effect of possible vibration on such eccentricity and the resulting unequal settlement.

877—Details of Design and Construction

(*a*) In counterforted walls the counterforts may be designed as T-beam sections and the vertical wall computed as a continuous slab and so reinforced. Properly anchored stirrups or tie bars should be provided of

required size and spacing to resist the earth thrust or soil pressure transferred by the slabs (wall or footing) to the counterforts.

(*b*) In buttressed walls the buttresses should be designed as rectangular beams and the vertical walls should be designed as a continuous slab reinforced for continuity.

(*c*) In designing the wall footing, consideration should be given to the necessity of tying the footing slab to the heel of the wall by adequate reinforcement when the downward pressure of the fill and the weight of concrete exceed the upward pressure of the soil. Where keys into the foundation are provided for resistance against sliding or for other reasons, they should be placed monolithically with the base.

(*d*) Longitudinal reinforcement for volume changes due to shrinkage and to changes in temperature should be provided in all reinforced concrete walls near the exposed face to an amount of not less than 0.50 sq in. area per ft of height with a maximum spacing of bars of 12 in. center to center. (It is desirable to use bars of small section and close spacing for this purpose.)

(*e*) No reinforcement should be less than 2 inches from any exposed face of the wall. Where concrete is in contact with soil, the reinforcement should be at least 3 inches from the surface.

(*f*) In reinforced concrete walls vertical construction joints with V notches at the face should be provided at sections preferably not over 30 ft apart, with reinforcement carried through the joint. Expansion joints with grooved lock joints should be provided not more than 100 ft apart for reinforced concrete walls; reinforcement should not be carried through expansion joints. In plain concrete walls similar expansion joints should be provided, preferably not more than 30 ft apart.

(*g*) Construction and expansion joints in the coping and balustrade of retaining walls should be placed over all joints in the walls. Additional joints in balustrade and copings may be desirable.

(*h*) Drainage should be provided at the backs of retaining walls, preferably by the use of layers of broken stone extending horizontally for the full length of the wall at an elevation where water can readily be disposed of, together with vertical layers extending up to the coping at intervals of about 15 ft along the wall. Weep holes at least 4 in. in diameter should be provided about 15 ft apart, or at least one in each panel of a counterforted wall, at such elevation that the drainage water may readily escape.

(*i*) Exposed faces of walls should be given a slight batter (about ¼ in. to 1 ft) to avoid appearance of tilting.

Unit Stresses

878—Allowable Working Stresses in Concrete and in Reinforcement

(*a*) The recommended unit stresses for concrete are based on the ultimate compressive strength, f'_c, of the concrete at 28 days. The methods of control, proportioning, and curing required to obtain the desired strength are given in Chapter III.

TABLE 7.—Recommended Working Stresses (Static and Impact Loads)

Modular Ratio: n for use in flexural calculations involving percentage of tensile steel, or tensile stress in the reinforcement. The values given are for concrete made from normal weight aggregates: for lightweight concrete, the values of n should be double those shown.

f'_c	n
= 2000–2400	= 15
= 2500–2900	= 12
= 3000–3900	= 10
= 4000–4900	= 8
above 5000	= 6

Concrete

***Flexure:* f_c**	
Extreme fiber stress in compression	$f_c = 0.45 f'_c$
Extreme fiber stress in tension (for plain concrete footings only)	$f_t = 0.03 f'_c$
***Shear:* v**	
Beams without web reinforcement and without end anchorage of longitudinal steel	$v_c = 0.02 f'_c$
Beams without web reinforcement but with end anchorage of longitudinal steel	$v_c = 0.03 f'_c$
Beams with properly designed web reinforcement, but without end anchorage of longitudinal steel	$v_c = 0.06 f'_c$
Beams with properly designed web reinforcement and with end anchorage of longitudinal steel (when v_c is in excess of 0.06 f'_c, web reinforcement should provide for total shear (see Sect. 817(*e*))	$v_c = 0.12 f'_c$
Flat slabs at distance d from edge of column capital, or dropped panel	$v_c = 0.03 f'_c$
Footings with longitudinal bars having no end anchorage	$v_c = 0.02 f'_c$
Footings with longitudinal bars having end anchorage	$v_c = 0.03 f'_c$
Combined footings and raft foundations designed as beam elements with properly designed web reinforcement and end anchorage	$v_c = 0.06 f'_c$
***Bond:* u**	
In beams and slabs and one-way footings:	
Plain bars	$u = 0.04 f'_c$ but not to exceed 160 lb per sq in.
Deformed bars	$u = 0.05 f'_c$ but not to exceed 200 lb per sq in.
In multiple-way footings:	
Plain bars	$u = 0.03 f'_c$ but not to exceed 160 lb per sq in.
Deformed bars	$u = 0.0375 f'_c$ but not to exceed 200 lb per sq in.
(Where end anchorage is provided (see Sect. 826), *one and one-half times* these values in bond may be used, but in no case to exceed 200 lb per sq in. for plain bars and 250 lb per sq in. for deformed bars.)	
***Bearing:* f_c**	
Full area loaded	$f_c = 0.25 f'_c$
Load on partial area, f_c variable (see Sect. 870), maximum	$f_c = 0.375 f'_c$
Axial Compression:	
In pedestals	$f_c = 0.25 f'_c$
In columns (see Sect. 854–855)	....

Reinforcement

Tension in Flexural Members, with or without axial loads:	
Structural grade steel bars	f_s = 18,000 lb per sq in.
Structural steel shapes	f_s = 18,000 lb per sq in.
Intermediate grade steel bars, and hard-grade bars (billet steel, rail steel, or axle steel)	f_s = 20,000 lb per sq in.
Wire mesh or bars not exceeding ½ in. in diameter when used in one-way solid slabs only	f_s = 50% of minimum yield point, but not to exceed 25,000 lb per sq in.
Tension in Web Reinforcement:	
All grades of steel	f_s = 16,000 lb per sq in.
Tension in Column Spirals (see Sect. 854)	
Compression in Column Verticals (see Sect. 854)	
Intermediate grade steel bars	f_s = 16,000 lb per sq in.
Hard-grade steel bars (billet steel, rail steel, or axle steel)	f_s = 20,000 lb per sq in.
Compression in Composite and Combination Columns (see Sect. 856–857)	
Compressive Reinforcement in Flexural Members (see Sect. 804(*c*))	

(*b*) The recommended working stresses in the steel reinforcement are based on the consideration of two important factors:

1. The yield point of the steel.
2. The extent to which cracks may develop on the tension face of flexural members.

The values given for tension are limited to approximately 50% of the yield point of the reinforcement, but with an upper limit of 20,000 lb per sq in. for important structural members, and 25,000 lb per sq in. for the special case of one-way slabs reinforced with wire mesh and small size bars. These upper limits are to apply for all grades of reinforcement regardless of yield point.

(c) *Static and Impact Loads.*—For static loads or for moving loads where appropriate allowances have been made for impact, the committee recommends the unit stresses given in Table 7.

(d) *Maximum Combined Stresses.*—Where stresses due to wind, earthquake, or other unusual forces, are combined with those due to static or impact loads, the sum of the stresses should not exceed the allowable values given in Table 7 by more than one-third.

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STANDARD SPECIFICATIONS FOR CONCRETE AND REINFORCED CONCRETE

MATERIALS

Cement

The cement to be used shall be one or more of the following types as designated by the Engineer.

201-S—Portland Cement

Normal portland cement shall conform to the Standard Specifications for Portland Cement of the American Society for Testing Materials (C9-38).

202-S—High Early Strength Portland Cement

High early strength portland cement shall conform to Standard Specifications of the American Society for Testing Materials (C74-39).

203-S—Special Cements

Special cements shall conform to the following requirements (see Recommended Practice—Sect. 202).

Admixtures

204-S—General

Materials used as admixtures shall conform to the following requirements (see Recommended Practice—Sect. 203).

Water

205-S—General

Water for concrete shall be clean and free from injurious amounts of oil, acid, alkali, organic matter, or other deleterious substances.

206-S—Mortar Strength

When subjected to the mortar strength test (see Sect. 229-S for method of test) the strength at 28 days of mortar specimens made with the water under examination and normal portland cement shall be at least 90% of the strength of similar specimens made with the same cement and with water of known satisfactory quality (see Recommended Practice—Sect. 204).

Fine Aggregate

207-S—General

Fine aggregate shall consist of natural sand, sand prepared from the product obtained by crushing stone, gravel, or air-cooled blast-furnace slag; or, subject to the approval of the Engineer, other inert materials having similar characteristics. The particular type or types to be furnished shall be specified by the Engineer (see also Sect. 226-S to 228-S).

208-S—Grading

Fine aggregate shall be graded from coarse to fine within the following limits (see Recommended Practice, Sect. 205 and 206).

Sieve Size	Total Passing (Percentage by Weight)
3/8 in.	100
No. 4	95–100
No. 16	45–80
No. 50	5–30
No. 100	0–8

209-S—Uniformity

For the purpose of controlling the grading of fine aggregate from any one source, a preliminary sample shall be submitted prior to actual deliveries. This sample shall be representative of the material which it is proposed to furnish. Any shipment of fine aggregate made during the progress of the work which shows a variation in fineness modulus greater than 0.20 either way from the fineness modulus of the preliminary sample shall be rejected or, at the option of the Engineer, may be accepted subject to such changes in concrete proportions as may be necessary by reason of failure to comply with the requirements of this section.

210-S—Deleterious Substances

Deleterious substances shall not be present in excess of the following amounts (see Recommended Practice, Sect. 205 and 208):

Description	Permissible Limits (Percentage by Weight)	
	Recommended	Maximum
Clay lumps	1	1½
Coal and lignite	¼	1
Material finer than No. 200 sieve		
(a) In concrete subject to surface abrasion	2	3
(b) All other classes of structures	3	5
Other deleterious substances (as may be specified)	....	....

211-S—Organic Impurities

The fine aggregate when tested in accordance with the method of test for organic impurities (see Sect. 229-S(*c*)) shall show a color not darker than the standard color unless the material complies with the mortar strength test specified in Sect. 212-S.

212-S—Mortar Strength

Mortar specimens made with the fine aggregate when tested in accordance with the mortar strength test (see Sect. 229-S) shall have an average compressive strength of at least 90% of the strength of similar specimens made with the same cement and Ottawa sand graded as specified in A.S.T.M. Tentative Method of Test for Compressive Strength of Portland Cement Mortars (A.S.T.M. Designation: C109-37T) when tested at an age

of not less than 7 days when normal portland cement is used and not less than 3 days when high early strength cement is used. (These requirements are intended to assure the use of fine aggregate of satisfactory quality from the standpoint of concrete strength. The 10% tolerance is allowed to cover unavoidable variations in normal testing procedure.)

213-S—Soundness

(*a*) The fine aggregate when subjected to five alternations of the sodium sulfate soundness test (see Sect. 229-S) shall conform to the following requirements (see Recommended Practice, Sect. 205 and 209):

	Permissible Limits (Percentages)	
	Recommended	Maximum
Average weighted loss	8	12

(*b*) Fine aggregate failing to meet the requirement shown in (*a*) above may be accepted, provided it is shown by evidence satisfactory to the Engineer that concrete of comparable proportions made from similar aggregate from the same source has been exposed to natural weathering for a period of at least 5 years without appreciable disintegration.

(*c*) The requirements for soundness given in (*a*) and (*b*) above may be waived in the case of aggregate for use in structures or portions of structures not exposed to weathering.

Coarse Aggregate

214-S—General

Coarse aggregate shall consist of crushed stone, gravel, air-cooled blast-furnace slag, or, subject to the approval of the Engineer, other inert materials having similar characteristics. The particular type or types to be furnished shall be specified by the Engineer (see also Sect. 220-S to 225-S).

215-S—Grading

Coarse aggregate of the sizes designated shall conform to the following requirements:

Designated Sizes	Percentage by Weight Passing Laboratory Sieves Having Square Openings										
	4-In.	3½-In.	2½-In.	2-In.	1½-In.	1-In.	¾-In.	½-In.	⅜-In.	No. 4	No. 8
No. 4–½ in.	..	..	..	..	..	..	100	90–100	40–75	0–15	0–5
No. 4–¾ in.	..	..	..	..	..	100	90–100	..	20–55	0–10	0–5
No. 4–1 in.	..	..	..	..	100	90–100	..	25–60	..	0–10	..
No. 4–1½ in.	..	..	..	100	95–100	..	35–70	..	10–30	0–5	..
No. 4–2 in.	..	..	100	95–100	..	35–70	..	10–30	..	0–5	..
¾–1½ in.	..	..	..	100	90–100	20–55	0–15	..	..	..	..
1–2 in.	..	..	100	90–100	35–70	0–15	..	..	..	..	..
2–3½ in.	100	90–100	..	0–15	..	..	..	..	..	..	..

216-S—Deleterious Substances

Deleterious substances shall not be present in excess of the following amounts (see Recommended Practice, Sect. 205 and 208):

	Permissible Limits (Percentage by Weight)	
	Recommended	Maximum
Soft fragments	2	5
Coal and lignite	¼	1
Clay lumps	¼	¼
Material finer than No. 200 sieve	½[a]	1[a]
Other deleterious substances (as may be specified)	..	..

[a] When the material finer than the No. 200 sieve consists essentially of crusher dust the maximum amounts permitted may be raised to ¾ and 1½ per cent, respectively.

217-S—Soundness

(*a*) The coarse aggregate when subjected to five alternations of the sodium sulfate test (see Sect. 229-S) shall conform to the following requirement (see Recommended Practice, Sect. 205 and 209):

Description	Permissible Limits Per Cent	
	Recommended	Maximum
Average weighted loss	12	15

(*b*) Coarse aggregate failing to meet the requirement shown in (*a*) above may be accepted, provided it is shown by evidence satisfactory to the Engineer that concrete of comparable proportions made from similar aggregate from the same source has been exposed to natural weathering for a period of at least 5 years without appreciable disintegration.

(*c*) The requirements for soundness given in (*a*) and (*b*) above may be waived in the case of aggregate for use in structures or portions of structures not exposed to weathering.

218-S—Weight per Cubic Foot of Slag

Blast-furnace slag graded as used shall meet the following requirements (see Recommended Practice, Sect. 205):

Description	Recommended Permissible Limits		Minimum Permissible Limits	
	Concrete subject to surface abrasion	Concrete not subject to surface abrasion	Concrete subject to surface abrasion	Concrete not subject to surface abrasion
Weight, lb per cu ft, not less than	75	70	70	65

219-S—Resistance to Abrasion

Crushed stone and gravel to be used in concrete subject to surface abrasion, such as pavements, heavy duty floors, structures subjected to the abrasive action of floating ice, etc., shall meet the following requirements for abrasion loss when tested for resistance to abrasion (see Sect. 229-S) (see Recommended Practice, Sect. 212):

Material	Permissible Limits (Percentage by Weight)	
	Recommended	Maximum
Crushed stone	5	9
Gravel (100% uncrushed)	10	20
Gravel (100% crushed)	20	30
Gravel (...% crushed)	....	....

Rubble and Cyclopean Aggregate

220-S—Rubble Aggregate

Rubble aggregate shall consist of clean, hard, durable stone or gravel retained on a 6-in. square opening and with individual particles weighing not more than 100 lb.

221-S—Cyclopean Aggregate

Cyclopean aggregate shall consist of clean, hard, durable stone or gravel with individual particles weighing more than 100 lb.

Aggregates for Lightweight Concrete

222-S—General

Lightweight aggregates shall consist of pumice, lava, tufa, cinders, specially prepared slag, coke, burnt clay, or other products having similar characteristics. Lightweight aggregates shall conform to the requirements of the general specifications for grading (Sect. 208-S to 215-S), organic impurities (Sect. 211-S), soundness (Sect. 213-S), and for mortar strength, as specified in Sect. 212-S, except that the minimum strength of the lightweight aggregate mortar made with aggregate in a saturated and surface dry condition shall be at least 70% of that of Ottawa sand mortar (see Recommended Practice, Sect. 210).

223-S—Deleterious Substances

Lightweight aggregates shall conform to the following requirements (see Sect. 229-S for method of test):

Description	Fine Aggregate Per Cent	Coarse Aggregate Per Cent
Clay lumps, not more than	1.5	1.0
Coal, not more than	1.5[a]	1.5[a]
Material finer than No. 200 sieve, not more than	4.0	2.0
Other deleterious substances (as may be specified)	....	....

[a] Shall not apply to aggregate derived from coal (cinders, coke, etc.).

224-S—Weight per Cubic Foot

Lightweight aggregates shall meet the following requirements (see Sect. 210, Recommended Practice):

Description	(lb.)
Maximum weight per cubic foot, dry and loose,	
Fine aggregate	70
Coarse aggregate	55

Aggregates for Use in Fireproofing

225-S—Fireproofing Aggregate

(*a*) Aggregates meeting the requirements of Sect. 207-S to 219-S, inclusive, or Sect. 222-S to 224-S, inclusive, of these specifications are suitable for use in fireproof construction. When used in fireproof construction they shall be divided into two groups as follows:

Group 1: Blast-furnace slag, limestone, calcareous gravel, trap rock, burnt clay or shale, cinders containing not more than 25% of combustible material and not more than 5% of volatile material, and other materials meeting the requirements of these specifications and containing not more than 30% of quartz, chert, flint, and similar materials.

Group 2: Granite, quartzite, siliceous gravel, sandstone, gneiss, cinders containing more than 25%, but not more than 40% of combustible material and not more than 5% of volatile material and other materials meeting the requirements of these specifications, and containing more than 30% of quartz, chert, flint, and similar materials.

(*b*) The fire protection requirements shown on the drawings are based on the use of aggregates in Group 1,—Group 2. (The Engineer shall strike out one of the two groups indicated; see Recommended Practice, Sect. 505, for recommendations regarding minimum protection of reinforcement when using aggregates of either group.)

METHODS OF SAMPLING AND TESTING

226-S—Methods of Sampling

Methods of sampling portland cement and high-early-strength portland cement shall be in accordance with A.S.T.M. Standard Methods of Sampling and Physical Testing of Portland Cement (A.S.T.M. Designation: C77-39).

227-S—

Methods of sampling aggregates shall be in accordance with A.S.T.M. Tentative Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials Including Some Material Survey Methods (A.S.T.M. Designation: D75-39T).

228-S—Methods of Testing

Portland cement and high-early-strength portland cement shall be tested in accordance with A.S.T.M. Standard Methods of Sampling and Physical Testing of Portland Cement (A.S.T.M. Designation: C77-39).

229-S—

Fine and coarse aggregate shall be tested in accordance with the following:

(*a*) *Grading.*—A.S.T.M. Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregate (A.S.T.M. Designation: C136-39).

(*b*) *Uniformity of Grading—Fineness Modulus.*—The fineness modulus of the aggregate shall be determined by adding the total percentages retained on the following U. S. Standard sieves and dividing by 100: 3-in., 1½-in., ¾-in., ⅜-in., No. 4, No. 8, No. 16, No. 30, No. 50, and No. 100.

(*c*) *Organic Impurities.*—A.S.T.M. Standard Method of Test for Organic Impurities in Sands for Concrete (A.S.T.M. Designation: C40-33).

(*d*) *Coal and Lignite.*—A.S.T.M. Standard Method of Test for Coal and Lignite in Sand (A.S.T.M. Designation: C123-39).

(*e*) *Fineness.*—A.S.T.M. Standard Method of Test for Amount of Material Finer than No. 200 Sieve in Aggregates (A.S.T.M. Designation: C117-37).

(*f*) *Clay Lumps.*—The percentages of clay lumps shall be determined by examining the various fractions which remain after the test for grading. Any particles that can be broken up with the fingers shall be classified as clay lumps and the total percentages by weight of all clay lumps shall be determined on the basis of the total original weight of the sample.

(*g*) *Mortar Strength.*—A.S.T.M. Standard Method of Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar (A.S.T.M. Designation: C87-39).

(*h*) *Soundness—Fine and Coarse Aggregate.*—A.S.T.M. Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (A.S.T.M. Designation: C88-39T).

(*i*) *Resistance to Abrasion*

1. *Stone.*—A.S.T.M. Standard Method of Test for Abrasion of Rock by Use of the Deval Machine (A.S.T.M. Designation: D2-33).
2. *Gravel.*—A.S.T.M. Tentative Method of Test for Abrasion of Gravel by Use of the Deval Machine (A.S.T.M. Designation: D289-37T).

(*j*) *Weight per Cubic Foot of Slag.*—A.S.T.M. Standard Method of Test for Unit Weight of Aggregate (A.S.T.M. Designation: C29-39).

(*k*) *Weight per Cubic Foot of Lightweight Aggregates.*—A.S.T.M. Standard Method of Test for Unit Weight of Aggregate (A.S.T.M. Designation: C29-39). (Note: Jigging procedure in Sect. 6 to be followed.)

(*l*) *Amount of Combustible and Volatile Materials in Aggregates.*—A.S.T.M. Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (A.S.T.M. Designation: D271-37).

Metal Reinforcement

230-S—Bar and Mat Reinforcement

Metal reinforcement shall be plain or deformed steel bars or cold-drawn steel wire, or fabricated forms of these materials, as required by the drawings or the specifications or both. These materials shall conform in

quality to Standard Specifications of the American Society for Testing Materials of the following applicable titles and serial designations:

Bars:

Billet-Steel Bars for Concrete Reinforcement.......A15-39
Rail-Steel Bars for Concrete Reinforcement........A16-35
Axle-Steel Bars for Concrete Reinforcement........A160-39

Wire:

Cold-Drawn Steel Wire for Concrete Reinforcement..A82-34

Fabricated Materials:

Fabricated Steel Bar or Rod Mats for Concrete Reinforcement.................................A184-37
Welded Steel Wire Fabric for Concrete Reinforcement.A185-37

231-S—Structural Units

When cast-iron or structural steel sections are used, as in the case of composite or combination columns, these materials shall conform in quality to Standard Specifications of the American Society for Testing Materials of the following applicable titles and serial designations:

Cast-Iron Pit-Cast Pipe for Water and Other Liquids..A44-39T
Steel for Bridges and Buildings..................A7-39

PROPORTIONING, MIXING, CURING, AND TESTING CONCRETE

Proportioning: Alternate A

Specifications Based on the Strength and Water Content of the Concrete

301-SA—Concrete Quality

It is the intent of this specification to secure, for every part of the work, concrete of homogeneous structure which, when hardened, will have the required strength and resistance to weathering. To this end, the limiting strengths and water contents shown in Table A are specified. (The Engineer should fill in the details of Table A to indicate the characteristics of the concrete which are desired for each part of the work; see Sect. 303, 304, 306, and 307 of Recommended Practice for suggestions. The Engineer should strike out one of the words "Flexural" or "Compressive" in the table.) The values given in Table A are based on the use of normal portland cement, aggregates, and water which meet the requirements of Sect. 201-S to 229-S of this specification.

TABLE A

Class (1)	Minimum Allowable Strength, Compressive Flexural at 28 Days (lb per sq in.) (2)	Maximum Allowable Net Water Content per Sack of Cement; gal. (3)	Consistency, Range in Slump; in. (4)	Maximum Size of Aggregate; in. (5)

The strengths shall be determined in accordance with the requirements of Sect. 321-S to 325-S. The maximum allowable net water content is the total water in the mixture at the time of mixing, not including the water absorbed by the aggregates.

302-SA—Determination of Proportions

(*a*) The proportions of cement, aggregates, and water necessary to produce concrete conforming to the requirements of Table A shall be determined by means of laboratory tests of concrete made with the cement and aggregates to be used on the work. At least 35 days prior to the beginning of concrete work the Contractor shall submit, for approval, samples of the materials he proposes to use. Prior to the beginning of work he shall also submit a statement of the proportions proposed for the concrete mixture. This shall be accompanied by a report in detail from an approved testing laboratory or inspection service showing for at least three different water contents the 7-day and 28-day concrete strengths obtained when using

the materials proposed for the work. The strength determinations shall be based on not less than 5 concrete test specimens for each age and for each water content. The strength tests shall be made in accordance with Sect. 321-S to 325-S except for the method of sampling.

(*b*) The Engineer shall have the right to make check tests of concrete, using the same materials, and to order such changes as may be necessary to meet the requirements of the specifications.

(*c*) The ratio between the 7-day and 28-day strengths established by the preliminary tests shall be used to determine the 7-day strengths necessary to satisfy the 28-day strength requirements of Table A. This ratio shall be modified as the work progresses as may be indicated by the results of tests made in accordance with Sect. 320-S.

303-SA—Prior Test Records

In the event that the Contractor furnishes reliable test records of concrete made with materials from the same sources and of the same quality in connection with current work, all or a part of the strength tests specified hereinbefore may be waived by the Engineer.

304-SA—Workability of Concrete

The concrete shall be of such consistency and composition that it can be worked readily into the corners and angles of the forms and around the reinforcement without permitting the materials to segregate or free water to collect on the surface. Subject to the limiting requirements of Table A, the Contractor shall adjust the proportions of cement and aggregate as may be necessary to produce a mixture which will be easily placeable at all times, due consideration being given to the methods of placing and compacting used on the work.

305-SA—Changes in Consistency for Mechanical Vibration

When high frequency mechanical vibration is used for compacting concrete, the limiting consistencies in Table A may be modified subject to the approval of the Engineer. The proportions and consistencies, however, shall be such that with the vibratory equipment in use the full requirements of Sect. 304-SA shall be satisfied.

306-SA—Changes in Proportions or Materials by the Engineer

If, during the progress of the work, it is found impossible to secure concrete of the required workability and strength with the materials being furnished by the Contractor, the Engineer may order such changes in proportions or materials, or both, as may be necessary to secure the desired properties, subject to the limiting requirements shown in Table A. Any changes so ordered shall be made at the Contractor's expense, and no extra compensation will be allowed by reason of such changes.

307-SA—Changes in Materials by the Contractor

If, during the progress of the work, the Contractor desires to use materials other than those originally approved, or if the materials from the sources

originally approved change in characteristics, he shall submit, for approval, evidence satisfactory to the Engineer that the new combination of materials will produce concrete meeting the requirements shown in Table A, and will not bring about objectionable changes in the color or appearance of the structure.

308-SA—Changes in Requirements

Regardless of the limitations of Table A, at any time during the progress of the work, the owner shall have the right to make such changes in the materials or proportions, or both, as he may consider necessary to meet the requirements of the structure. In such case, the Contractor shall be compensated in accordance with the terms of the contract for the additional cost of materials and additional handling and placing costs, if any, entailed by changed materials or mixtures, or both, which are not covered by the specification requirements shown in Table A for the respective portions of the work involved.

309-SA—Concrete Made with High Early Strength Portland Cement

When high early strength portland cement is used in lieu of normal portland cement, the requirements given in Table A shall apply, except that the "Minimum allowable strength at 28 days" specified for normal portland cement shall be the minimum allowable strength at 7 days. The ages at time of test specified in Sect. 302-SA shall be 3 days and 7 days in lieu of the 7-day and 28-day ages specified for normal portland cement.

PROPORTIONING: ALTERNATE B

Specifications Based Primarily on Designated Cement Content

301-SB—Proportions

All concrete shall be proportioned as indicated in Table B.

302-SB—Cement Factor

The cement factor given in column 3 of Table B indicates the weight of cement per cubic yard of concrete when the concrete is in a freshly mixed condition. The volume of the freshly mixed concrete shall be assumed to be the absolute volume of the cement, plus the volume of the mixing water, plus the displaced volumes of the saturated, surface-dry aggregates. The quantity of mixing water to be used in this calculation shall not include water absorbed by the aggregates.

303-SB—Variations in Proportions

In order to obtain proper workability and a smooth, dense, homogeneous, plastic mixture, free from segregation, the percentage of fine aggregate may be varied within the limits indicated with the approval of the Engineer. The estimated 28-day strengths indicated in column 2 of Table B are the strengths used in the design calculations.

The Engineer will verify strengths by tests made during the progress of the work and in accordance with the requirements of Sect. 321-S to 325-S. When a ratio between 7-day and 28-day strengths has been established by these tests or by preliminary tests, the 7-day strengths may be taken as a satisfactory indication of the 28-day strengths. In the event that cement in excess of that indicated in Table B is necessary to produce concrete of the indicated strength or workability, the cement factor shall be increased as directed by the Engineer, and the Contractor shall receive extra compensation for the additional cement so used. In the event that cement less than that indicated in Table B is sufficient to produce concrete of the indicated strength or workability the Engineer may order a reduction in the cement factor, in which case there shall be an adjustment in contract price equal to the actual difference in cost to the Contractor of the required cement and aggregates.

TABLE B[a]

Class of Concrete	Estimated 28-Day Compressive Flexural Strength (lb per sq in.)[a]	Cement Factor; Sacks Cement (94 lb) per cu yd Concrete	Max. Water per 94 lb Cement (Gal.)	Max. Size Agg. (In.)	Fine Agg.; % Total Agg. by Weight (range)[a]	Slump, Range (In.)	Approx. Wts. Saturated Surface-Dry Agg. per Sack (94 lb) of Cement[b]	
							Fine Agg. (lb)	Coarse Agg. (lb)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

[a] The Engineer should fill in the details of Table B to indicate the characteristics of the concrete which are desired for each part of the work. See Sect. 305 and 307, Recommended Practice, for suggestions. The Engineer should strike out one of the words "Flexural" or "Compressive" in column 2 as may be required.

[b] The approximate weights in columns 8 and 9 have been determined on the assumption that the aggregates are in a saturated, surface-dry condition and have a bulk specific gravity of 2.65.

304-SB—Water Content and Slump Range

The maximum quantity of water per 94 lb of cement specified in Table B shall include the free water in the aggregates; however, moisture absorbed by the aggregates shall not be included. The slump range indicated in Table B is intended as a guide to the Contractor for the determination of placing and compacting procedures and equipment. Within the range specified, the slump shall be as directed by the Engineer. If the concrete has a greater slump than the maximum indicated, the quantity of water shall be reduced to meet the slump requirements. If the concrete has a smaller slump than the minimum indicated, changes in the mixture shall be made as specified in Sect. 303-SB.

305-SB—Changes in Consistency for Mechanical Vibration

When high frequency mechanical vibration is used for compacting the concrete, the proportions and consistencies in Table B shall be modified as required to produce the type of concrete specified in Sect. 303-SB and 304-SB.

306-SB—Concrete Made with High Early Strength Portland Cement

When high early strength portland cement is used in lieu of normal portland cement, the requirements given in Table B shall apply, except that the estimated 28-day strength indicated for normal portland cement concrete shall be the estimated 7-day strength when high early strength portland cement concrete is used. The ages at time of test specified in Sect. 303-SB shall be 3 days and 7 days, respectively, in lieu of the 7-day and 28-day ages specified for normal portland cement.

310-S—Measurements of Materials

(*a*) Materials shall be measured by weighing, except as otherwise specified or where other methods are specifically authorized by the Engineer. The apparatus provided for weighing the aggregates and cement shall be suitably designed and constructed for this purpose. Each size of aggregate and the cement shall be weighed separately. The accuracy of all weighing devices shall be such that successive quantities can be measured to within 1% of the desired amount. Cement in standard packages (sack) need not be weighed, but bulk cement and fractional packages shall be weighed. The mixing water shall be measured by volume or by weight. The water measuring device shall be susceptible of control accurate to ±0.5% of the capacity of the tank. All measuring devices shall be subject to approval.

(*b*) Where volumetric measurements are authorized by the Engineer, the weight proportions shall be converted to equivalent volumetric proportions. In such case, suitable allowance shall be made for variations in the moisture condition of the aggregates, including the bulking effect in the fine aggregate.

Mixing

311-S—Equipment

The mixing equipment shall be capable of combining the aggregates, cement, and water within the specified time into a thoroughly mixed and uniform mass, and of discharging the mixture without segregation.

312-S—Machine Mixing (at Site or at Central Mixing Plant)

Unless otherwise authorized by the Engineer, the mixing of concrete shall be done in a batch mixer of approved type which will insure a uniform distribution of the material throughout the mass. The equipment at the mixing plant shall be so constructed that all materials (including the water) entering the drum can be accurately proportioned and be under control. The entire batch shall be discharged before recharging. The volume of the mixed material per batch shall not exceed the manufacturer's rated capacity

of the mixer. Except as qualified in Sect. 314-S, mixing of each batch shall continue for the periods indicated below during which time the drum shall rotate at a peripheral speed of about 200 ft per minute. (When, in the judgment of the Engineer, longer mixing times are necessary he should so specify.) The mixing periods shall be measured from the time when all of the solid materials are in the mixer drum, provided that all of the mixing water shall be introduced before one-fourth of the mixing time has elapsed.

Mixing time shall be as follows:

(1) For mixers of a capacity of 1 cu yd or less, 1 min; and,

(2) For mixers of capacities larger than 1 cu yd, the time of mixing shall be increased 15 sec for each additional half-cubic yard capacity or fraction thereof.

313-S—Truck Mixing

Truck mixers, unless otherwise authorized by the Engineer, shall be of the revolving drum type, watertight, and so constructed that the concrete can be mixed to insure a uniform distribution of materials throughout the mass. All solid materials for the concrete shall be accurately measured in accordance with Sect. 310-S and charged into the drum at the proportioning plant. Except as subsequently provided, the truck mixer shall be equipped with a tank for carrying mixing water. Only the prescribed amount of water shall be placed in the tank unless the tank is equipped with a device by which the quantity of water added can be readily verified. The mixing water may be added directly to the batch, in which case a tank shall not be required. Truck mixers may be required to be provided with means by which the mixing time can be readily verified by the Engineer. The maximum size of batch in truck mixers shall be in accordance with the specified rating (see Sect. 308 of Recommended Practice). Truck mixing shall be continued for not less than fifty revolutions after all ingredients, including the water, are in the drum. The speed shall not be less than 4 r.p.m., nor more than a speed resulting in a peripheral velocity of the drum of 225 ft per minute. Not more than 150 revolutions of mixing shall be at a speed in excess of 6 r.p.m. Mixing shall begin within 30 min after the cement has been added either to the water or aggregate. (When cement is charged into a mixer drum containing water or surface-wet aggregate and when the temperature is above 90°F., or when high-early-strength portland cement is used, this limit shall be reduced to 15 min; the limitation on time between the introduction of the cement to the aggregates and the beginning of the mixing may be waived when, in the judgment of the Engineer, the aggregates are sufficiently free from moisture, so that there will be no harmful effects on the cement.)

314-S—Partial Mixing at the Central Plant

When a truck mixer, or an agitator provided with adequate mixing blades, is used for transportation, the mixing time at the stationary machine mixer may be reduced to 30 seconds and the mixing completed in a truck mixer or agitator. The mixing time in the truck mixer or agitator equipped

with adequate mixing blades shall be as specified for truck mixing in Sect. 313-S.

315-S—Time of Hauling Ready-Mixed Concrete

Concrete transported in a truck mixer, agitator, or other transportation device shall be discharged at the job within 1½ hours after the cement has been added to the water or the aggregates (see Sect. 308 of Recommended Practice). The maximum volume of mixed concrete transported in an agitator shall be in accordance with the specified rating.

316-S—Hand Mixing

When hand mixing is authorized it shall be done on a watertight platform and in such a manner as to insure a uniform distribution of the materials throughout the mass. Mixing shall be continued until a homogeneous mixture of the required consistency is obtained.

317-S—Retempering

The retempering of concrete or mortar which has partially hardened, that is, mixing with or without additional cement, aggregate, or water, will not be permitted.

Curing of Concrete

318-S—Protection

(*a*) All concrete, except as noted under (*c*) below, placed under these specifications shall be so protected that the temperature at the surface will not fall below 50°F., or that there will be no loss of moisture from the surface for the periods indicated below.

1. Where normal portland cement is used—7 days.
2. Where high-early-strength portland cement is used—3 days.

(*b*) The Contractor shall submit for the approval of the Engineer the methods he proposes to use for protecting the concrete against low temperatures.

(*c*) The requirement in (*a*) and (*b*) above concerning the temperature at the surface is intended to apply to the placing of concrete in those seasons of the year, or in such places where the possibility of freezing or continued low temperatures is to be expected. It is not intended to apply where temperatures below 40°F. are a rarity. In any case, however, concrete must be protected from freezing temperatures at any time during the first 72 hours where normal portland cement is used, or 24 hours where high early strength portland cement is used.

(*d*) Protection against loss of moisture from the surface of the concrete shall be accomplished by keeping the surface continuously wet. One of the following methods shall be used:

(Here the Engineer shall list the methods which he is willing to approve; see Recommended Practice, Sect. 309(*b*), for suggestions).

FIELD TESTS OF CONCRETE

320-S—Field Tests

During the progress of construction the Engineer will have tests made to determine whether the concrete as being produced complies with the standards of quality specified in Sect. 301-S (A or B). These tests will be made in accordance with Sect. 321-S to 325-S. The Contractor shall cooperate in the making of such tests to the extent of allowing free access to the work for the selection of samples and storage of specimens, and in affording protection to the specimens against injury or loss through his operations.

321-S—Test Pieces

Three cylinders or beams will generally be made for each class of concrete used in any one day's operation. In special cases this normal number of control specimens may be exceeded when in the opinion of the Engineer such additional tests are necessary. The Contractor, however, shall not be required to furnish for such additional tests more than 2 cu ft of concrete from each 100 cu yd of concrete being placed.

322-S—Sampling and Curing of Test Pieces

Samples of concrete for test specimens shall be taken at the mixer, or in the case of ready mixed concrete, from the transportation vehicle during discharge. When, in the opinion of the Engineer, it is desirable to take samples elsewhere, they shall be taken as directed by him. The test specimens shall be molded immediately after the sample is taken, placed in a protected spot and kept under moist curing conditions at approximately 70°F. for 24 hr, whereupon they shall be removed to the testing laboratory. (The temperature and other storage conditions of the test specimens during the first few days is a vital factor in the strength results. It is the intent of these specifications that the requirements herein specified shall be complied with minutely; however, the exact details of storage and transportation facilities shall be those best suited to the individual requirements.) In the laboratory they shall be kept under standard moist curing conditions. at 70°F. (± 5°F.) until time of test and shall be tested in the damp condition.

323-S—Age

The tests shall be made at the age of the concrete corresponding to that for which the strengths are specified in Table A or Table B.

324-S—Compression Tests

For compression tests, the size of cylinder and the manner of molding, capping, and testing shall be in accordance with the A.S.T.M. Standard Method of Test for Compressive Strength of Concrete (A.S.T.M. Designation: C39-39).

325-S—Flexure Tests

For flexure tests, the size and shape of specimens and the manner of molding and testing shall be in accordance with the A.S.T.M. Standard

Method of Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third-Point Loading; A.S.T.M. Designation C78-39).

ENFORCEMENT OF STRENGTH REQUIREMENTS

326-SA—Failure to Meet Requirements

Should the strengths shown by the test specimens made and tested in accordance with the provisions of Sect. 320-S fall below the values given in Sect. 301-SA, the Engineer shall have the right to require changes in proportions as outlined in Sect. 306-SA to apply on the remainder of the work. Furthermore, the Engineer shall have the right to require additional curing, as specified in Sect. 328-SA, on those portions of the structure represented by the test specimens which failed. In the event that such additional curing does not give the strength required the Engineer shall have the right to require strengthening or replacement of those portions of the structure which fail to develop the required strength.

327-SA—Definition of Failure

The specimens will be considered to have failed when the average strength for any period of placing is less than the following values:

Number of Days Consecutive Placing of Any One Class of Concrete	Percentage of Strength Specified in Section 301-SA
1	85
2	90
3	95
5 or more	100

328-SA—Additional Curing

When additional curing of portions of the structure is ordered by the Engineer in accordance with Sect. 326-SA, it shall be done at the Contractor's expense and no claim for extra compensation for such additional curing shall be allowed. Such additional curing shall consist in an extension of the periods of protection specified in Sect. 318-S as may, in the judgment of the Engineer, be necessary. In no case, however, shall the Contractor be required to provide such additional curing beyond a total of 21 days, except where the average strengths of specimens, representing concrete placed on any three consecutive days, fall below 80% of the value specified in Table A, Sect. 301-SA. In this case, curing shall be continued until cores drilled from portions of the structure involved show an average strength equal to that specified in Table A. Cores for this purpose shall have a diameter of approximately three times the maximum size of aggregate and shall be secured, capped, and tested in accordance with Standard Methods of Securing Specimens of Hardened Concrete from the Structure (A.S.T.M. Designation: C42-39).

FORMS AND PLACING

FORMS

401-S—General

Forms shall conform to the shape, lines, grades, and dimensions of the concrete as called for on the drawings. Lumber used in forms for exposed surfaces shall be dressed to a uniform thickness, and shall be free from loose knots or other defects. Joints in forms shall be horizontal or vertical where appearance of the finished surface is of importance. For unexposed surfaces and rough work, undressed lumber may be used. Lumber once used in forms shall have nails withdrawn, and surfaces to be in contact with concrete thoroughly cleaned before being used again.

402-S—Design

(*a*) Forms shall be sufficiently tight to prevent leakage of mortar. They shall be properly braced or tied together so as to maintain the desired position and shape during and after placing concrete. In the case of very long spans where no intermediate supports are possible, the probable deflection in the forms due to the weight of the fresh concrete shall be taken into account so that the finished members shall conform accurately to the desired line and grade. If adequate foundation for shores cannot be secured, trussed supports shall be provided.

(*b*) Bolts and rods shall preferably be used for internal ties; they shall be so arranged that when the forms are removed no metal shall be within 1 in. of any surface. Shores supporting successive stories shall be placed directly over those below, or so designed and placed that the load will be transmitted directly to them.

403-S—Moldings

Unless otherwise specified suitable moldings or bevels shall be placed in the angles of forms to round or bevel the edges of the concrete.

404-S—Oiling

The inside of forms shall be coated with nonstaining mineral oil or other approved material, or in case of wood forms they shall be thoroughly wetted (except in freezing weather). Where oil is used, it shall be applied before the reinforcement is placed.

405-S—Inspection

Temporary openings shall be provided at the base of column and wall forms and at other points where necessary to facilitate cleaning and inspection immediately before depositing concrete.

406-S—Form Removal

The removal of forms shall not be started until the concrete has attained the necessary strength to support its own weight and any construction live loads.

DEPOSITING CONCRETE

407-S—General

(*a*) Before beginning placement of concrete, hardened concrete and foreign materials shall be removed from the inner surface of the mixing and conveying equipment.

(*b*) Before depositing concrete, debris shall be removed from the space to be occupied by the concrete; forms if constructed of lumber shall be thoroughly wetted (except in freezing weather) or oiled. Reinforcement shall be thoroughly secured in position and approval by the Engineer obtained before concrete is placed.

408-S—Removal of Water

Water shall be removed from the space to be occupied by the concrete before concrete is deposited, unless otherwise directed by the Engineer. Any flow of water into an excavation shall be diverted through proper side drains to a sump, or be removed by other approved methods which will avoid washing the freshly deposited concrete. If directed by the Engineer water vent pipes and drains shall be filled by grouting or otherwise after the concrete has thoroughly hardened.

409-S—Handling

(*a*) Concrete shall be handled from the mixer, or in the case of ready-mixed concrete, from the transporting vehicle, to the place of final deposit as rapidly as practicable by methods which shall prevent the separation or loss of the ingredients. (See Sect. 315-S.) Under no circumstances shall concrete that has partially hardened be deposited in the work. Concrete shall be deposited in the forms as nearly as practicable in its final position to avoid rehandling. It shall be so deposited as to maintain, until the completion of the unit, a plastic surface approximately horizontal. Forms for walls or thin sections of considerable height shall be provided with openings or other devices that will permit the concrete to be placed in a manner that will prevent segregation and accumulations of hardened concrete on the forms or metal reinforcement above the level of the concrete.

(*b*) Concrete, regardless of the type of transporting vehicle, shall have, when deposited in the forms, the quality required.

410-S—Chuting

When concrete is conveyed by chutes, the equipment shall be of such size and design as to insure a continuous flow in the chute. The chutes shall be of metal or metal lined and the different portions shall have approximately the same slope. The slope shall not be less than one vertical to two hori-

zontal and shall be such as to prevent the segregation of the ingredients. The discharge end of the chute shall be provided with a baffle plate to prevent segregation. If the distance of the discharge end of the chute above the surface of the concrete is more than three times the thickness of the layer being deposited, but not more than 5 ft above the surface of the concrete, a spout shall be used, and the lower end maintained as near the surface of deposit as practicable. When the operation is intermittent, the chute shall discharge into a hopper. The chute shall be thoroughly cleaned before and after each run and the debris and any water used shall be discharged outside the forms.

411-S—Pneumatic Placing

(*a*) Where concrete is conveyed and placed by pneumatic means the equipment shall be suitable in kind and adequate in capacity for the work. The machine shall be located as close as practicable to the place of deposit. The position of the discharge end of the line shall not be more than 10 ft from the point of deposit. The discharge lines shall be horizontal or inclined upwards from the machine.

(*b*) At the conclusion of placement the entire equipment shall be thoroughly cleaned.

412-S—Pumping

Where concrete is conveyed and placed by mechanically applied pressure the equipment shall be suitable in kind and adequate in capacity for the work. The operation of the pump shall be such that a continuous stream of concrete without air pockets is produced. When pumping is completed, the concrete remaining in the pipeline, if it is to be used, shall be ejected in such a manner that there will be no contamination of the concrete or separation of the ingredients. After this operation the entire equipment shall be thoroughly cleaned (see Recommended Practice, Sect. 403).

413-S—Compacting

(*a*) Concrete during and immediately after depositing shall be thoroughly compacted by means of suitable tools. For thin walls or inaccessible portions of the forms, where spading, rodding, or forking is impracticable, the concrete shall be worked into place by vibrating, or hammering the forms lightly opposite the freshly deposited concrete. The concrete shall be thoroughly worked around the reinforcement, and around embedded fixtures, and into the corners of the forms.

(*b*) Accumulations of water on the surface of the concrete due to water gain, segregation, or other causes, during placement and compacting, shall be prevented as far as possible by adjustments in the mixture. Provision shall be made for the removal of such water as may accumulate so that under no circumstances will concrete be placed in such accumulations (see Recommended Practice, Sect. 404).

(*c*) The Engineer shall indicate which of the following requirements shall, may, or shall not apply:

$$\text{Concrete}\left\{\begin{array}{l}\text{shall}\\ \text{may}\\ \text{shall not}\end{array}\right\}\text{be compacted by mechanical vibration.}$$

When mechanical vibration is used the number and type of vibrators shall be subject to the approval of the Engineer.

414-S—Depositing Continuously

Concrete shall be deposited continuously, or in layers of such thickness that no concrete will be deposited on concrete which has hardened sufficiently to cause the formation of seams and planes of weakness within the section. If a section cannot be placed continuously, construction joints may be located at points as provided for in the drawings or approved by the Engineer. Such joints shall be made in accordance with the provisions in Sect. 508-S to 510-S.

415-S—Depositing in Cold Weather

Concrete when deposited shall have a temperature of not less than 50°F. nor more than 120°F. In freezing weather, suitable means shall be provided for maintaining the concrete at the temperature and for the periods specified in Sect. 318-S, or until the concrete has thoroughly hardened. Before placing the concrete, the forms shall be free from frost and ice, and after the concrete is placed it shall be protected on all exposed sides by straw, tarpaulins, or other means. Manure, if used for such protection, shall not come in contact with the concrete. The methods of heating the materials and protecting the concrete shall be approved by the Engineer. Salts, chemicals, or other foreign materials shall not be mixed with the concrete for the purpose of preventing freezing.

416-S—Bonding

Before depositing new concrete on or against concrete which has hardened, the forms shall be retightened. The surface of the hardened concrete shall be roughened as required by the Engineer, in a manner that will not leave loosened particles of aggregate or damaged concrete at the surface. It shall be thoroughly cleaned of foreign matter and laitance, and saturated with water. To insure an excess of mortar at the juncture of the hardened and the newly deposited concrete, the cleaned and saturated surfaces, including vertical and inclined surfaces, shall first be thoroughly covered with a coating of mortar or neat cement grout against which the new concrete shall be placed before the grout has attained its initial set.

417-S—Protection and Curing

The concrete shall be protected and cured in accordance with requirements of Sect. 318-S.

418-S—Placing Cyclopean Concrete

Cyclopean aggregate shall be thoroughly embedded with no stone closer than one foot to any surface, and with a space of at least 6 in. between adjacent stones. Stratified stone shall be laid on its natural bed. Cyclopean aggregate shall be carefully placed to avoid injury to forms or adjoining masonry.

419-S—Placing Rubble Concrete

Rubble aggregate shall be thoroughly embedded in the concrete.

The individual stones shall not be closer than four inches to any surface or adjacent stones. Rubble aggregate shall be carefully placed to avoid injury to forms or adjacent masonry.

420-S—Depositing Concrete Under Water

(*a*) When it is necessary to deposit concrete under water the methods, equipment, materials, and proportions of the mixture to be used shall be submitted to and be approved by the Engineer before the work is started.

(*b*) Concrete shall not be placed in water having a temperature below 35°F. The temperature of the concrete, when deposited, shall not be less than 60°F. nor more than 120°F.

(*c*) The concrete shall contain not less than 7 sacks or 658 lb of cement per cubic yard. The volume or weight of the coarse aggregate shall not be less than one and one-half, nor more than twice that of the fine aggregate. The concrete shall be mixed with sufficient water to produce a concrete having a slump of not less than 4 inches and not more than 7 inches.

(*d*) Cofferdams or forms shall be sufficiently tight to reduce the flow or current of water to 10 ft per min through the space into which concrete is to be deposited. Cofferdams or forms in still water shall be sufficiently tight to prevent loss of mortar through the walls. Pumping will not be permitted while concrete is being placed, nor until 24 hours thereafter.

(*e*) Concrete shall be deposited continuously until it is brought to the required height. While depositing, the top surface shall be kept as nearly level as possible and the formation of seams avoided. The methods to be used for depositing concrete under water shall be one of the following:

1. *Tremie.*—The tremie shall be watertight and large enough to allow a free flow of concrete. It shall be kept filled with concrete at all times while depositing. The concrete shall be discharged and spread by so moving the tremie as to maintain as nearly as practicable a uniform flow and avoid dropping the concrete through water. If the charge is lost, while depositing, the tremie shall be withdrawn and refilled. The slump of concrete shall be maintained between 5 and 7 in.

2. *Drop Bottom Bucket.*—The top of the bucket shall be open. The bottom doors shall open freely downward and outward when tripped. The bucket shall be completely filled and slowly lowered to avoid backwash. It shall not be dumped until it rests on the surface upon which the concrete is to be deposited and when discharged shall be withdrawn

slowly until well above the concrete. The slump of concrete shall be maintained between 4 and 6 in.

3. *Bags.*—Bags of at least 1-cu ft capacity, of jute or other coarse cloth, shall be filled about two-thirds full of concrete and securely tied. They shall be placed carefully in header-and-stretcher courses so that the whole mass is interlocked. Bags used for this purpose shall be free from deleterious materials.

(*f*) To minimize the formation of laitance great care shall be exercised to disturb the concrete as little as possible while it is being deposited. Upon completion of a section of concrete, all laitance shall be entirely removed before work is resumed.

421-S—Depositing Concrete Exposed to Corrosive Waters or Soils

Where concrete may be exposed to the action of corrosive waters or soils, special care shall be taken to place it in accordance with Sect. 407-S to 416-S. Wherever possible placing shall be continuous until completion of the section or until the concrete is at least 18 in. above ground or water level. Corrosive waters or soils shall be kept from contact with the concrete during placement and for a period of at least 72 hr thereafter.

422-S—Pneumatically Applied Mortar

(*a*) *General.*—This section refers to premixed sand and cement pneumatically applied by suitable mechanism and competent operators, and to which mixture the water is added immediately previous to its expulsion from the nozzle.

(*b*) *Quality of Materials.*—The quality of cement, sand, and water shall be in accordance with Sect. 201-S to 213-S.

(*c*) *Proportions.*—The proportions of cement to sand shall be based on dry and loose volumes and shall not be less than one to four for encasement of steel members, one to three for concrete repair, nor one to four and a half for canal linings.

(*d*) *Water Content.*—The water content shall be maintained at a practicable minimum and not in excess of three gallons per sack of cement as placed.

(*e*) *Mixing.*—The cement and sand shall be thoroughly mixed before being charged into the machine. The sand shall contain not less than 4% moisture.

(*f*) *Nozzle Velocity.*—The velocity of the material as it leaves the nozzle must be maintained uniform at a rate determined for the given job conditions to produce minimum rebound.

(*g*) *Nozzle Position.*—The nozzle shall be held in such a position and at such distance that the stream of flowing material will impinge at approximately right angles to the surface being covered without excessive impact.

(*h*) *Rebound Sand.*—Rebound or accumulated loose sand shall be removed from the surface to be covered prior to placing of the original or succeeding layers of mortar.

(*i*) *Forms.*—The forms shall be structurally sufficient and of such design that rebound or accumulated loose sand can freely escape or be readily removed. Shooting strips should be used at corners, edges, and on surfaces where necessary to obtain true lines and proper thickness.

(*j*) *Joints.*—The pneumatically applied mortar at the end of any day's work or similar stopping periods shall be sloped off to a thin edge. Before placing an adjacent section this sloped portion shall be thoroughly cleaned and wetted.

(*k*) *Bond.*—Surfaces to which pneumatically applied mortar is to be bonded shall be thoroughly cleaned of dirt, paint, grease, organic matter, and loose particles. Absorptive surfaces shall be wetted before the application of the mortar.

(*l*) *Curing.*—Pneumatically applied mortar shall be so applied, protected, and cured as to prevent its temperature falling below 50°F., or a loss of moisture from the surface for the periods indicated below:

1. Where normal portland cement is used, 7 days.
2. Where high early strength portland cement is used, 3 days.

Pneumatically applied mortar shall be applied only with the permission of the Engineer when the air temperature is 50°F. or less.

(*m*) *Reinforcement.*—The reinforcement when required shall be adequate from the standpoint of structural requirements and shall consist of mesh or round bars, spaced not less than 2 in. nor more than 4 in. apart either way, and having a diameter not less than that of No. 12 wire. The area of the reinforcement shall be at least 0.2% of the cross-sectional area of the mortar. The reinforcement shall be at least ¼ in. from the unexposed surface of the mortar and at least ¾ in. from the exposed surface.

NOTE: For recommended practice for pneumatically applied mortar see Sect. 406.

DETAILS OF CONSTRUCTION

Handling Metal Reinforcement

501-S—Cleaning

Metal reinforcement before being positioned shall be free from loose mill and rust scale and from coatings, including ice, that destroy or reduce the bond. Where there is delay in depositing concrete, reinforcement shall be reinspected and cleaned when necessary.

502-S—Fabrication

Reinforcement shall be accurately formed to the dimensions indicated on the drawings. Stirrups and tie bars shall be bent around a pin having a diameter not less than two times the minimum thickness of the bar. Bends for other bars shall be made around a pin having a diameter not less than 6 times the minimum thickness except for bars larger than 1 in. in which case the bends shall be made around a pin of eight bar diameters. All bars shall be bent cold.

503-S—Straightening and Rebending

Metal reinforcement shall not be straightened or rebent in a manner that will injure the material. Bars with kinks, or bends not shown on the drawings, shall not be used. Heating of the reinforcement will be permitted only when the entire operation is approved by the Engineer.

504-S—Placing Reinforcement

(*a*) Metal reinforcement shall be accurately positioned and secured against displacement by using annealed iron wire ties or suitable clips at intersections, and shall be supported by concrete or metal supports, spacers, or metal hangers. Where indicated on the drawings or required by the specifications, metal clips or supports shall not be placed in contact with the forms.

(*b*) The minimum center-to-center distance between parallel bars shall be 2½ times the diameter of round or 3 times the side dimensions for square bars, but in no case shall the clear spacing between the bars be less than 1½ times the maximum size of the coarse aggregate nor less than 1 in. in beams and girders, nor less than 1½ in. in columns. Bars parallel to the exterior surface of any member not exposed to the weather shall be embedded at least one bar diameter for round bars, or diagonal dimension for square bars, but in no case less than ¾ in. from the exterior surface, nor less than shown on the drawings, or as required by Sect. 505-S.

505-S—Moisture Protection

(*a*) At those surfaces of footings and other principal structural members in which the concrete is deposited directly against the ground, metal reinforcement shall have a minimum covering of 3 in. of concrete. At other surfaces of concrete exposed to the ground or to severe weathering conditions, metal reinforcement shall be protected by not less than 2 in. of concrete for bars over ⅝ in. in diameter, and 1½ in. for bars ⅝ in. in diameter or less. At underside of slabs exposed to weather one inch shall be provided.

506-S—Splicing of Reinforcement

When it is necessary to splice reinforcement at points other than shown on the drawings, the character of the splice shall be determined by the

Engineer. In such splices the bars shall be placed in contact and wired. Splices in adjacent bars shall be staggered.

507-S—Future Bonding

Exposed reinforcement intended for bonding with future extensions shall be effectively protected from corrosion.

Construction Joints

508-S—Location of Joints

(*a*) *Columns.*—Joints in columns shall be made at the underside of floor members and at floor levels. Haunches and column capitals shall be considered as part of and continuous with the floor or roof. At least two hours shall elapse after depositing concrete in columns or walls before depositing the concrete in the floor system.

(*b*) *Floors.*—Construction joints in the floor system shall be located at or near the middle of the span in slabs, beams, or girders, unless a beam intersects a girder at this point, in which case the joint in the girder shall be offset a distance equal to twice the width of the beam and provision satisfactory to the Engineer shall be made for shear by the use of inclined web reinforcement across the joint.

509-S—Procedure in Forming Joints

The procedure specified in Sect. 416-S for bonding new concrete to old shall be followed in the formation of all joints. The reinforcement shall continue through the joint. For concrete without reinforcement, shearing strength shall be provided by means of a concrete key or dowel bars as the Engineer may direct.

510-S—Extra Steel at Construction Joints

Where a construction joint is required in a section of a building more than 100 ft long or more than 100 ft between expansion joints, special reinforcement shall be placed at right angles to the joint and extending in both directions from the joint 40 diameters in the case of deformed bars and 50 diameters in the case of plain bars. This reinforcement shall be placed near the face of the member opposite from the main tensile reinforcement. The cross-sectional area of such reinforcement shall not be less than 0.5% of the section of the members cut by the joint.

511-S—Watertight Construction Joints

(*a*) Where a horizontal construction joint is required to resist water pressure, special care shall be taken in finishing the surface to which the succeeding concrete is to be bonded. The consistency of the concrete shall be carefully controlled so that it can be placed with a minimum of puddling with no free water showing. The surface shall be protected from loss of moisture and from mechanical injury. In applying the new concrete the procedure specified in 416-S shall be followed.

(*b*) Vertical construction joints shall not be made in watertight construction unless shown on the plans or authorized by the Engineer.

APPENDICES

APPENDIX 1—EFFECT OF VARIOUS SUBSTANCES ON PORTLAND CEMENT CONCRETE AND SUGGESTED PROTECTIVE TREATMENTS WHERE REQUIRED

Substance	Effect on Unprotected Concrete	Protective Treatment
	Petroleum Oils	
Light fuel oils above 30° Baumé	None—some loss from penetration	Fluosilicate, spar varnish, linseed oil, sodium silicate
Volatile oils—kerosene, benzine, naphtha, gasoline	None—considerable loss from penetration	Fluosilicate, spar varnish, sodium silicate, phenolformaldehyde varnish
Heavy oils—30° Baumé or heavier	None—very slight penetration	None
	Coal-Tar Distillates	
Phenol, cresol, lysol, creosote, carbolineum	Attack concrete slowly	Fluosilicate, sodium silicate, spar varnish, phenolformaldehyde varnish
Benzol, toluol, xylol, and cumol	None—some loss from penetration	Fluosilicate, sodium silicate, linseed oil, spar varnish
Pitch, anthracene, carbonzol, and paraffin	None	None
	Inorganic Acids	
Sulphuric, nitric	Disintegrates	Glass, vitrified brick or tile laid in litharge, lead, and rubber give effective protection for temperatures below 150°F. and for concentrations of 50% or less.
Sulphurous	Disintegrates	Glass, vitrified brick or tile laid in litharge, lead, and rubber give effective protection for all concentrations.
Hydrochloric	Disintegrates	Lead, rubber only for temperatures below 150°F. and for concentrations of 50% or less.
Hydrofluoric	Disintegrates	
	Organic Materials	
Acetic	Disintegrates slowly	Bituminous enamel, phenolformaldehyde varnish, spar varnish, rubber
Carbonic in water	Attacks concrete slowly	Asphalt, bituminous, or coal-tar paints, fluosilicate, sodium silicate, spar varnish, phenolformaldehyde varnish, resin
Lactic or tannic	Attacks concrete slowly	Above group; also linseed oil and paraffin
Fish oil	Very slight attack	Fluosilicate, sodium silicate, linseed oil
Lard and lard oil	Very slight attack	Above group
Foot oil	Very slight attack	Above group
Linseed	Slight attack	None
Resin	Slight attack	None
Cocoanut	Slight attack	Fluosilicate, sodium silicate, linseed oil
Olive	Slight attack	Above group; also spar or Bakelite varnish
Rape seed	Slight attack	Above group; also spar or Bakelite varnish
Cotton seed	Slight attack	None
Almond	Slight attack	Fluosilicate, sodium silicate, linseed oil, varnish
Poppy seed	Very slight attack	Above group
Walnut	Very slight attack	Above group
Soy-bean	Very slight attack	Above group
Peanut	Very slight attack	Above group
Oxalic	None	None
Carbonic (dry)	None	None

APPENDIX 1 (*Continued*)

Substance	Effect on Unprotected Concrete	Protective Treatment
Salts		
Soluble inorganic salts attack concrete to a greater or less extent in the following order: sulphates, sulphides, nitrates, chlorides, and carbonates.		
Sulphates of calcium, potassium, sodium, magnesium, copper, zinc, aluminum, manganese, iron, nickel, cobalt	Actively attack concrete	Suggested treatments are: fluosilicate, sodium silicate, linseed oil, bituminous applications, glass, vitrified brick or tile laid in litharge cement and rubber
Sulphates of ammonia	Disintegrate	Above group
Chlorides of magnesium, iron, mercury, copper, and ammonia	Slight attack	Above group
Nitrate of ammonia	Disintegrates	Above group
Sulphide ores and pyrite	Slight attack	Above group
Acid sulphate	Strong attack	Suggested treatments are: fluosilicate, sodium silicate, linseed oil, bituminous applications, glass, vitrified brick or tile laid in litharge cement and rubber.
Chlorides of sodium, potassium, calcium, strontium	None	None
Nitrates of calcium, potassium, and sodium	None	None
Soluble sulphides except sulphide of ammonia	None	None
Carbonates	None	None
Fluorides	None	None
Silicates	None	None
Miscellaneous		
Molasses	Slight attack	Suggested treatments are: fluosilicate, sodium silicate, linseed oil, bituminous applications, glass, vitrified brick or tile laid in litharge cement and rubber.
Sulphite liquor	Slight attack	Above group
Milk	Attacks slowly	Above group
Corn syrup and glucose	Slight attack	Above group
Silage juices	Attack slowly	Above group
Ammonia water	None	None
Wood pulp	None	None
Tanning liquors (non acid)	None	None
Alcohol	None	None

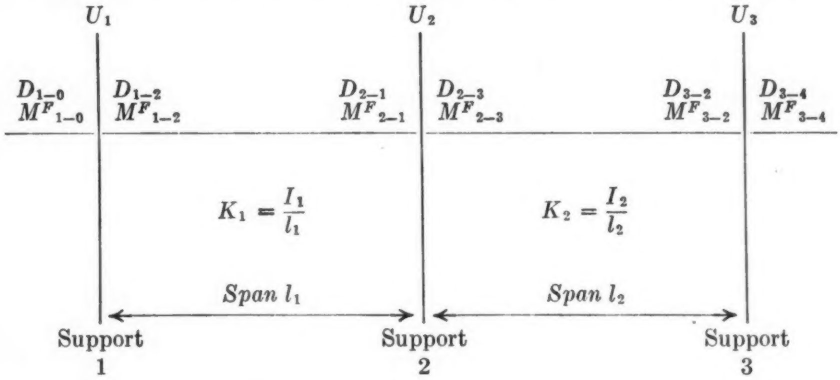
APPENDIX 2—SUPPORT MOMENTS IN CONTINUOUS BEAMS AND FRAMES

A number of methods of frame analysis are available to the designer such as Moment Distribution, Slope Deflection, Virtual Work, etc. For preliminary designs and also for final designs in the ordinary cases, the following approximate general method may be used. The method is based on moment distribution and is approximate to the extent that it includes only two cycles of distribution[5] for fixed end moments at three successive supports or joints.

The method is general in that it is applicable to the fixed end moments for any type of loading in the four spans adjacent to the three supports or joints under consideration.

[5] For a more complete treatment of this method, see "Continuous Frames of Reinforced Concrete," by Hardy Cross and N. D. Morgan (John Wiley and Sons, N. Y., 1932).

For notation refer to the following diagrams and definitions on next pages:



Let joints 1, 2, and 3 in the order shown mark the ends of two spans l_1 and l_2.

Let $M^F{}_{2-1}$ = fixed end moment at the left of joint 2 due to the loads in the span between supports 2 and 1.

$M^F{}_{2-3}$ = fixed end moment at the right of joint 2 due to the loads in the span between supports 2 and 3.

U_2 = algebraic sum of the fixed end moments at joint 2, i.e. $M^F{}_{2-1} + M^F{}_{2-3}$.

Similarly,

U_1 = algebraic sum of the fixed end moments at joint 1,

U_3 = algebraic sum of the fixed end moments at joint 3.

Fixed end moments are to be given positive sign if they tend to produce clockwise *rotation of the joint* and negative sign if counter clockwise.

The signs of U_1, U_2, and U_3 result from the addition of the two terms. If the clockwise term is the greater, the sign will be positive; if the counter clockwise term is greater, the sign will be negative.

$$K_1 = \frac{I_1}{l_1} = \text{stiffness factor for span 1–2.}$$

$$J_1 = \Sigma \frac{I}{l} \text{ for all members intersecting at joint 1.}$$

Similarly for other joints.

$$D_{1-2} = \text{Distribution factor at joint 1} = \frac{K_1}{J_1}$$

$$D_{2-1} = \text{Distribution factor at joint 2} = \frac{K_1}{J_2}$$

$$D_{2-3} = \text{Distribution factor at joint 2} = \frac{K_2}{J_2}$$

$$D_{3-2} = \text{Distribution factor at joint 3} = \frac{K_2}{J_3}$$

With this notation, the final moment M_{2-1} at the left of joint 2 can be obtained from the following equation:

$$M_{2-1} = M^F{}_{2-1} - D_{2-1}\,U_2 - \frac{D_{1-2}\,U_1}{2} + \frac{D_{2-1}}{2}\,(D_{1-2}\,U_1 + D_{3-2}\,U_3)\ldots(1)$$

Similarly,

$$M_{2-3} = M^F{}_{2-3} - D_{2-3}\,U_2 - \frac{D_{3-2}\,U_3}{2} + \frac{D_{2-3}}{2}\,(D_{3-2}\,U_3 + D_{1-2}\,U_1)\ldots(2)$$

Collecting terms, these equations can be written:

$$M_{2-1} = M^F{}_{2-1} - \frac{D_{1-2}\,U_1}{2} + \frac{D_{2-1}}{2}\,(D_{1-2}\,U_1 + D_{3-2}\,U_3 - 2\,U_2)\ldots.(3)$$

$$M_{2-3} = M^F{}_{2-3} - \frac{D_{3-2}\,U_3}{2} + \frac{D_{2-3}}{2}\,(D_{1-2}\,U_1 + D_{3-2}\,U_3 - 2\,U_2)\ldots.(4)$$

APPENDIX 3—MAXIMUM MOMENT COEFFICIENTS FOR ONE-WAY SLABS (SOLID OR RIBBED) OF EQUAL SPANS CARRYING UNIFORMLY DISTRIBUTED LOADS

The coefficients given in the table below are for the special case of equal spans and uniformly distributed loads. They are based on the assumption of continuity over the supports with negligible restraints at end and intermediate supports. The numerical values given are coefficients of $w_1 L^2$ and $w_2 L^2$, respectively, in which w_1 equals the dead load, and w_2 equals the live load per unit of area.

No. Spans	End Span					Interior Span			
	End Support Neg.	Mid-Span Pos.	Mid-Span Neg.	First Int. Support Pos.	First Int. Support Neg.	Mid-Span Pos.	Mid-Span Neg.	Typical Support Pos.	Typical Support Neg.
Dead Load									
1	−0.040	0.125							
2	−0.040	0.075			−0.125				
3	−0.040	0.085			−0.100	0.030			
4 or more	−0.040	0.080			−0.110	0.040[a] 0.046[a]			−0.080
Live Load									
1	−0.040	0.125	0.000						
2	−0.040	0.100	−0.030	0.000	−0.125				
3	−0.040	0.105	−0.025	0.017	−0.120	0.080	−0.050		
4 or more	−0.040	0.105	−0.020	0.015	−0.120	0.085	−0.045	0.036	−0.115

[a] 0.046 for 5 or more spans.

To adapt the table for use in cases where the dead load is slightly different on the several spans w_1 may be taken as the least dead load carried by one span of the series under consideration, and w_2 as the difference between w_1 and the greatest unit total load on any of the spans in the series.

APPENDIX 4—CURING PORTLAND CEMENT CONCRETE[6]

1. *General*

These specifications for Heat Curing and Wet Curing are based on requirements when normal portland cements are used.

When moderate low-heat cements are used, the curing time herein specified shall be increased 25%.

When high-early-strength portland cement is used, the curing period shall be not less than 40% of that specified for normal portland cement.

2. *Heat Curing*

Concrete, when deposited in massive structures, shall have a temperature of not less than 40°F.

When deposited in structures less than 6 feet in thickness the following table for temperatures will govern:

Temperature of Air (Degrees F.)	Minimum Temperature of Concrete When Placed (Degrees F.)
Below 30	70
Between 30 and 45	60
Above 45	45

In freezing weather, or when there is likelihood of freezing temperatures, within the specified curing period, suitable and sufficient measures must be provided for maintaining all concrete surfaces at a temperature of not less than 50°F. for a period of not less than 5 days after the concrete is placed, when normal portland cement is used, and not less than 48 hr when high-early-strength portland cement is used.

The temperature of concrete surfaces shall be determined by thermometers placed against the surfaces of the concrete.

Provision shall be made in form construction to permit the removal of small sections of forms to accommodate the placing of thermometers against concrete surfaces at locations designated by the Engineer.

After thermometers are placed, the apertures in forms shall be covered in a way to closely simulate the protection afforded by the forms.

In determining the temperatures at angles and corners of a structure, thermometers should be placed not more than 8 in. from the angles and corners.

Temperature readings shall be taken and recorded at intervals to be designated by the Engineer, over the entire curing period specified, and the temperatures so recorded shall be interpreted as the temperature of the concrete surfaces where thermometers were placed.

When protection from cold is needed to insure meeting these specification requirements, all necessary materials for covering or housing must be delivered at the site of the work before concreting is started and must be effectively applied or installed, together with such added heat furnished as may be necessary without depending in any way upon the heat of hydration during the first

[6] Manual Am. Ry. Eng. Assn., 1939; Specifications for Portland Cement Concrete, Plain and Reinforced, Sect. 8, page 25.

24 hr after concrete is placed, when normal portland cement is used, or the first 18 hr when high-early-strength portland cement is used.

When heat is supplied by steam or salamanders, covering or housing of the structure shall be so placed as to permit free circulation of air above and around the concrete within the enclosure, but to the exclusion of air currents from without, excepting that where salamanders are used, sufficient ventilation shall be provided to carry off gases. Special care shall be exercised to exclude cold drafts from angles and corners and from all projecting reinforcing steel.

When salamanders are used, water vessels must be placed over them or other means provided to maintain a high humidity within enclosures.

3. *Wet Curing*

When not otherwise specified, all concrete surfaces, when not protected by forms, must be kept constantly wet for a period of not less than 7 days after concrete is placed, when normal portland cement is used, and not less than 67 hr when high-early-strength portland cement is used.

The wet curing period for all concrete which will be in contact with brine drip, sea water, salt spray, alkali or sulfate bearing soils or waters, or similar destructive agents, shall be increased to 50% more than the periods specified for normal exposures.

When wood forms are left in place during the curing period they shall be kept sufficiently damp at all times to prevent openings at the joints and drying of the concrete.

Inspection shall be made of all exposed surfaces at intervals as directed by the Engineer, and job records shall be kept indicating whether surfaces were wet at times of inspection, and if not wet, stating reasons why.

When wet curing is impracticable, liquid surface applications to prevent or minimize evaporation may be used in lieu of wet curing only when approved by the Engineer.

APPENDIX 5—LIST OF SPECIFICATIONS CITED

American Society for Testing Materials

A7-39 —Specifications for Steel for Bridges and Buildings

A15-39 —Specifications for Billet-Steel Bars for Concrete Reinforcement

A16-35 —Specifications for Rail-Steel Bars for Concrete Reinforcement

A44-39T—Specifications for Cast-Iron Pit-Cast Pipe for Water and Other Liquids (Tentative)

A82-34 —Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement

A160-39 —Specifications for Axle-Steel Bars for Concrete Reinforcement

A184-37 —Specifications for Fabricated Steel Bar or Rod Mats for Concrete Reinforcement

A185-37 —Specifications for Welded Steel Wire Fabric for Concrete Reinforcement

C9-38 —Specifications for Portland Cement

C29-39 —Method of Test for Unit Weight of Aggregate

C39-39 —Method of Test for Compressive Strength of Concrete

C40-33 —Method of Test for Organic Impurities in Sands for Concrete
C42-39 —Method of Securing Specimens of Hardened Concrete from the Structure
C74-39 —Specifications for High-Early-Strength Portland Cement
C77-39 —Methods of Sampling and Physical Testing of Portland Cement
C78-39 —Method of Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third Point Loading)
C87-39 —Method of Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar
C88-39T—Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (Tentative)
C109-37T—Method of Test for Compressive Strength of Portland Cement Mortars (Tentative)
C117-37 —Method of Test for Amount of Material Finer than No. 200 Sieve in Aggregates
C123-39 —Method of Test for Coal and Lignite in Sand
C136-39 —Method of Test for Sieve Analysis of Fine and Coarse Aggregates
D2-33 —Method of Test for Abrasion of Rock by Use of the Deval Machine
D75-39T—Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials, Including Some Material Survey Methods (Tentative)
D271-37 —Methods of Laboratory Sampling and Analysis of Coal and Coke
D289-37T—Method of Test for Abrasion of Gravel by Use of the Deval Machine (Tentative)